The Economics of Livestock Disease: The Impact of a Regionalization Policy

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Abstract

An outbreak of Foot and Mouth disease in Canada would result in the closing of borders to trade in meat and livestock between Canada and the US. The loss of export market access would result in losses to Canadian producers and negatively affect Canada's reputation as a trading partner. Under a Regionalization Policy, trade could be allowed from disease-free regions of Canada during an outbreak. This would allow a limited amount of trade to continue and mitigate the losses to producers in uninfected areas. This thesis examined scenarios that involve various degrees of regionalization to determine the effects on producers, consumers and taxpayers. A partial-equilibrium model is used to determine the impact on economic welfare under each scenario and comparisons are made to help evaluate the relative outcomes of policies towards regionalization.

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List of Abbreviations

AAFC	Agriculture and Agri-Food Canada
AI	Avian Influenza
APHIS	Animal and Plant Health Inspection Service
ATQ	Agri-Traçabilité Québec
BSE	Bovine Spongiform Encephalopathy
CBA	Cost Benefit Analysis
CCIA	Canadian Cattle Identification Agency
CCIP	Canadian Cattle Identification Program
CFIA	Canadian Food Inspection Agency
CGE	Computable General Equilibrium
CLTS	Canadian Livestock Tracking System
CS	Consumer Surplus
CVM	Contingent Valuation Method
FMD	Foot & Mouth Disease
FMDV	Foot & Mouth Disease Virus
IO	Input-Output Model
LP	Linear Programming
OIE	Office International des Epizooties
PAM	Policy Analysis Matrix
PEM	Partial Equilibrium Model
PS	Producer Surplus
ROW	Rest Of World
SAM	Social Accounting Matrix
SPS	Sanitary and Phytosanitary
TS	Total Surplus
USDA	United States Department of Agriculture
WHL	West Hawk Lake
WHLZI	West Hawk Lake Zoning Initiative
WTA	Willingness to Accept
WTO	World Trade Organization
WTP	Willingness to Pay

Chapter 1

Introduction

Canada is highly dependent on the United States as a trading partner for many goods and services. In 2011 approximately 73.1% of Canada's exports went to the US and approximately 62.5% of imports to Canada came from the US (Statistics Canada, 2013). In 2011 Canada exported approximately 28.5% of the beef and veal it produced, with approximately 74.2% of those exports going to the US (Agriculture and Agri-Food Canada, 2012c). The trade of meat and livestock with the US and other international markets could be completely halted in the event of an outbreak of an infectous livestock disease. Such a closure of a major export market for a product could cause considerable harm to the particular Canadian industry and the wider Canadian economy. For example, the discovery of Bovine Spongiform Encephalopathy (BSE)[1] in Canada in 2003 resulted in direct economic costs estimated at CAN$3.3 billion. Adding in losses to the cow-calf sector, the total costs were estimated at CAN$6.3 billion, with the loss of export market access accounting for a significant portion of the costs (Mitura and Pietro, 2004). If livestock movements can be monitored through a traceability system that shows where the animal was born and where it has moved then the spread of livestock diseases can be more easily contained. With livestock disease contained, trade could potentially be allowed from disease-free regions (regionalization) and the financial impact from trade loss would be reduced.

This thesis will examine the impacts to Canadian beef producers and consumers in the event of a Foot & Mouth Disease (FMD) outbreak with respect to access to export markets. It will look at a variety of scenarios ranging from trade being completely halted, to trade being allowed from portions of the country through a policy of regionalization.

The rest of the chapter will discuss FMD in more detail and how it has impacted various countries of the

[1] Also referred to as "Mad Cow Disease".

world, including a discussion of Canada's policies for dealing with a FMD outbreak. This will be followed by a discussion on livestock traceability and how it is used in Canada and other countries. Next will be a discussion of regionalization policy and the West Hawk Lake Zoning Initiative to monitor animal movements. This leads to an overview of the research questions being posed and the methodology that is used to examine the questions.

The final section of this chapter outlines the structure of the remaining chapters.

1.1 Background - Livestock Disease

Livestock disease refers to any illness which can affect the health of livestock and may or may not be spread to humans. Livestock disease can threaten human health and lead to significant losses in the sale of animal products due to loss of export markets. For example, a single case of BSE in Alberta on May 20 2003 resulted in immediate import restrictions from over 40 countries. The effects of the discovery of BSE spread beyond cattle producers and packers, affecting trucking, sales yards and brokers. Export losses in Canada amounted to an estimated \$2.5 billion dollars which further resulted in an estimated \$2 billion dollar loss in GDP, a \$5.7 billion dollar decline in total output in the Canadian economy, a \$1 billion dollar decline in labour income and a loss of 75,000 jobs. The total economic impact was estimated to be \$6.3 billion dollars (Mitura and Pietro, 2004).

The FMD outbreak of 2001 in the UK resulted in losses estimated to be at least £9 billion.[2] Compensation to farmers accounted for a significant portion of the estimated costs. Losses were felt throughout various supporting industries. Tourism was also affected due to the closure of parks and other public areas in order to contain the outbreak (Campbell and Lee, 2010).

Livestock disease can also result in losses due to reduced public consumption of meat products attributed to lack of consumer confidence in the safety of these products. These effects can last long after a disease outbreak is brought under control.

[2] \$20,455,200,000 Canadian dollars based on the historical 2001 conversion rate of 2.2728. Source: http://www.oanda.com/currency/historical-rates/

1.1.1 Foot & Mouth Disease (FMD)

FMD is a disease which affects cloven-hoofed animals such as cattle, goats, pigs, sheep, antelope, bison, deer and others. It is one of the most contagious livestock diseases and is caused by the Foot & Mouth Disease Virus (FMDV). The Animal and Plant Health Inspection Service (APHIS) states: "*Animals with FMD typically have a fever and blisters on the tongue and lips, in and around the mouth, on the mammary glands, and between the hooves. These blisters, called vesicles, pop and turn into red areas called erosions. Pain and discomfort from the vesicles and erosions lead to other symptoms such as depression, anorexia, excessive salivation, lameness, and reluctance to move or stand. Most affected animals will not die from FMD, but the disease leaves them weakened and unable to produce meat and milk the way they did before.*" (Animal and Plant Health Inspection Service, 2013) APHIS further states that recovering animals may take several months to recover weight that was lost and conception rates may be lowered.

An outbreak of FMD could lead to large production losses as well as the loss of access to export markets. Since livestock production and export is an important contributor to the Canadian economy, it is vital to prevent the outbreak of FMD and in the event of an outbreak to control it quickly.

In light of the global implications that livestock disease represents, the "Office International des Epizooties" (OIE)[3] was founded in 1924 to ensure that the most up-to-date information is readily available to all countries. The OIE works in conjunction with the World Trade Organization (WTO) to develop policies for animal trade and disease classification. In particular, the OIE has classified FMD as "one of the most contagious animal diseases with important economic losses" (OIE, 2009). The OIE works closely with international and regional organizations all around the world with offices in every continent.[4] Many countries will not import livestock products from countries unless their status is "FMD-free without vaccination".[5]

[3] In May 2003 the organization changed its name to "The World Organization for Animal Health" but still uses its historical acronym OIE. OIE will be used throughout this document.

[4] http://www.oie.int/eng/OIE/en_about.htm

[5] The reason for this restriction is that blood tests cannot distinguish vaccinated animals from infected animals. Many countries will not take the risk of importing animals that could be disease carriers.

1.1.2 Past FMD Outbreaks

FMD is endemic in some countries whereas in other countries a case has not been reported in several decades. This section provides a brief overview on notable FMD outbreaks in various countries.

Japan

Nishiura and Omori (2010) discuss the relatively recent FMD outbreaks in Japan, which had been FMD-free for many decades but recently experienced two outbreaks. The 2000 outbreak was considered mild and did not spread far geographically. The 2010 outbreak was considerably larger and caused the country to lose its "FMD-free without vaccination" status for nearly 10 months.[6] The outbreak began in the Miyazaki Prefecture on March 31 2010 (Day 0) when a farmer reported a water buffalo that was experiencing fever and reduced milk production to the Miyazaki Prefectural Livestock Hygiene Service Center (LHSC). The farm was inspected and four water buffalo were identified with the same symptoms but it was not believed to be caused by FMD. Over the next few days more infected animals were found on nearby farms and laboratory testing was performed. Positive confirmation of the FMD virus was determined April 20 (Day 20) and measures went into effect to control the spread. Culls, movement controls and surveillance of infected properties were used to stop the spread of FMD but because the number of infected properties was so large a state of emergency was called on May 18 (Day 48). By day 52 vaccination was begun on all susceptible animals within 10 km of infected properties. Vaccinations and cullings were completed June 30 (Day 91). (Nishiura and Omori, 2010)

A 2011 report by the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS), indicates that the outbreak lasted 11 weeks with 292 infected farms and 211,608 infected or susceptible animals culled. The delay in identifying the FMD virus was cited as the reason for the rapid spread of the disease (Animal and Plant Health Inspection Service, 2011).

[6] Trade was suspended on April 20 2010 when FMD was positively confirmed in laboratory testing. The OIE reinstated Japan's "FMD-free without vaccination" status on February 4 2011 (Animal and Plant Health Inspection Service, 2011).

United Kingdom

The UK has had a small number of FMD outbreaks. There had been minor yearly outbreaks between 1929 and 1953 followed by a major outbreak in 1967. The 1967 outbreak started on Bryn Farm, Oswestry, Shropshire. The source was determined to be pig food contaminated by FMD infected Argentine lamb.[7] Nearly 500,000 animals were slaughtered over nine months to eradicate the disease, with more than 2,000 cases reported. This would be the worst outbreak in that country's history until the 2001 outbreak (Reynolds and Tansey, 2003).

The 2001 FMD outbreak was more severe than the 1967 outbreak. The outbreak is believed to have originated in a pig finishing unit at Burnside Farm, Heddon on the Wall, Northumberland which is located in North East England. The first confirmation of disease was February 23 2001. Unprocessed or inadequately processed waste food from an unknown source was identified as the origin of the outbreak. The disease is believed to have spread through the movement of pigs as well as airborne transmission to sheep at Prestwick Hall Farm, Ponteland, Northumberland. It continued to spread when infected sheep were sold and moved throughout England, Wales and southern Scotland (DEFRA, 2002). There were many factors that contributed to the size of the epidemic. The first case was identified on February 23 but the disease is believed to have been introduced in late January or early February. By that time infected sheep had already been moving through the country as was common at that time of year. Weather conditions were also favourable for the virus to survive (Gibbens et al., 2001). As of June 2001 there had been 1,777 confirmed cases and 3.4 million animals slaughtered (Blake, Sinclair, and Sugiyarto, 2003).

By the end of the outbreak there were 2,030 reported cases with 6 million animals culled (consisting of 4.9 million sheep, 0.7 million cattle and 0.4 million pigs). Losses were estimated at £3.1 billion. An additional £2.5 billion was paid by the government for compensation and clean up costs (DEFRA, 2004). The outbreak also significantly impacted rural tourism. As a result of efforts to contain the disease many popular rural areas were quarantined affecting local residents and foreign visitors. Blake, Sinclair, and Sugiyarto (2003)

[7] Another theory about the source of the outbreak was that it was arranged by Ernst Stavros Blofeld, an agent of SPECTRE. In the 1969 film "On Her Majesty's Secret Service" Blofeld recounts his guilt to James Bond: "Remember that disagreeable outbreak of foot-and-mouth disease in England last summer? I shall instruct them (United Nations), in very convincing terms, exactly how I arranged that." ©1969, Eon Productions.

estimate tourism expenditures in 2001 were down £7.7 billion.

South America

FMD has been a persistent problem in some South American countries. Sumner, Bervejillo, and Jarvis (2005) discuss the problems faced in that continent. After years of unsuccessful attempts to eradicate FMD for good, Uruguay, Argentina, Brazil and Paraguay made a big push to coordinate their efforts with newer vaccines that became available in the late 1980s. Vaccinations were administered to all cattle, and culls were done whenever an FMD outbreak occurred. Uruguay was the first country to achieve "FMD-free without vaccination" status in 1994. By April 2000, Argentina, Paraguay and southern Brazil also achieved that status. Unfortunately FMD was still prevalent in the neighbouring regions of Bolivia and northern Brazil because of poor border controls and monitoring. The disease came back to Argentina in July 2000 and eventually to Paraguay and Uruguay in 2001. Culling was no longer effective in controlling the rapidly spreading disease so vaccination was once more used as a fallback, putting these countries back where they started (Sumner, Bervejillo, and Jarvis, 2005).

According to the OIE the only countries in South America currently "FMD-free without vaccination" are Chile and Guyana. Some other countries have zones with that status but there are still zones where vaccination is being used to control FMD (OIE, 2012).

United States

Segarra and Rawson (2001) briefly discuss the history of FMD outbreaks in the US through a Congressional Report for Congress. Since 1870 there have been nine FMD outbreaks brought under control through culls and quarantining. The most serious outbreak started in Michigan in 1914 where it eventually spread to 22 states with 172,000 cattle, sheep and swine having been culled before the outbreak was eliminated in 1915. The last US outbreak was in 1929 in Montebello, California where hogs contracted the disease by eating contaminated meat that came from an Argentinian ship. The outbreak was eliminated within a month through the culling of 3,600 animals (Segarra and Rawson, 2001).

Canada

The last outbreak of FMD in Canada occurred in Saskatchewan in 1951-1952. On November 26 1951 the presence of a disease believed to be vesicular stomatitus was reported on a farm approximately 55 km NE of Regina. The farm was quarantined but outbreaks occurred on other farms. It was not until February 1952 that FMD was suspected due to the appearance of other symptoms. Material was collected and sent to Hull, Québec for laboratory examination on February 14 and four days later a quarantine was imposed for all affected areas. On February 25, FMD was confirmed and culls of animals in all affected areas were ordered. Further outbreaks occurred over the next few months with the last case being reported on April 29 1952. Canada was declared FMD-free on August 19 1952. In total 1,313 cattle, 294 swine, 97 sheep, 1 goat, 2,373 fowl and 15,828 eggs were culled or destroyed. The cost of eradication alone was 1 million dollars but the total loss was estimated at 722 million dollars taking into account the losses due to export market closure and producer support pricing (Sellers and Daggupaty, 1990). Producer support pricing refers to compensation paid to producers by the government to offset losses.

These examples show how FMD can spread quickly resulting in large animal culls in order to eliminate the spread. The 2001 outbreak in the UK resulted in significant losses to the livestock industry as well as losses for the rural tourism industry. The examples from South America show how FMD can be a persistent problem without full cooperation from all countries. Countries that depend on livestock trade must be vigilant in their efforts to prevent outbreaks and quickly control them if they do occur.

1.1.3 Canada's Policy Response to an FMD Outbreak

The Canadian Food Inspection Agency (CFIA) is the department of the Canadian government which deals with inspection and other services related to food safety, and animal and plant health. The CFIA has detailed policies for animal disease outbreaks and control procedures. Canada has FMD Free Status and the CFIA employs strict measures to ensure this continues. Live animals coming into the country are subject to import controls, and meat being imported from a country that has FMD must meet strict guidelines. People entering Canada must declare where they have travelled and any food items they are bringing into the country. Trained border personnel attempt to ensure that concealed animals and food products which may have come into contact with FMD are not smuggled into the country. The CFIA's policy regarding vaccination of cattle against FMD is that it is not used as a preventative measure against FMD. The exception to this rule would be in the event of an overwhelming outbreak. The reasons for this policy are as follows (Canadian Food Inspection Agency, 2012b):

1. there are several types of the virus and it is not possible to predict which type Canadian animals may be exposed to from year to year. To maximize their effectiveness, vaccines must be targeted to the specific type of FMD that is present;

2. if an animal is exposed to the virus shortly after vaccination, it may become a carrier and spread the virus without showing any signs of infection;

3. vaccination is not effective in a small percentage of animals;

4. for most animals, two vaccinations at prescribed intervals are required, although this depends upon the species and the effectiveness of the vaccine for the particular virus. This is time-consuming and expensive for producers;

5. routine blood tests cannot distinguish vaccinated animals from infected animals, and therefore vaccinated animals and their products would not meet export requirements for most of Canada's trading partners;[8]

6. producers and veterinarians would not become aware that the disease had entered the country as quickly as they would if every animal were susceptible and showed signs of the disease.

In the event of an outbreak, the CFIA's policy is to eradicate the disease through a policy known as "stamping out" in order to re-establish disease-free status as soon as possible. Specifically this policy entails (Canadian Food Inspection Agency, 2012a):

- humane destruction of all infected and exposed animals;

- surveillance and tracing of potentially infected or exposed animals;

[8] A country that vaccinates its animals to control FMD would not have the status "FMD-free without vaccination" and would not be eligible to export to many countries that require this status.

- quarantine and animal movement controls to prevent spread;
- decontamination of infected premises; and
- zoning to define infected and disease-free areas.

Following the outbreak, Canada would not regain it's "FMD-free" status until three months after the last case was detected and resolved. Any animal with FMD must be tracked and slaughtered. Producers who lose animals due to FMD control are eligible to be compensated for the market value of their loss (see below). This policy was put in place to encourage producers to report animal disease when it is detected. Early detection will result in more effective controls to contain and destroy the disease.

The market value of the culled animal is determined by a CFIA veterinary inspector and two other evaluators and is based on a number of factors which includes the animal's genetic background, age and production history. Producers may also be awarded compensation for other expenses incurred such as disposal costs, transportation, slaughter, labour and equipment. Producer compensation may not exceed the maximum level determined by the Compensation for Destroyed Animals Regulations.[9]

1.2 Livestock Traceability

Traceability is a key component of controlling livestock disease. During an outbreak it is of considerable importance to identify and isolate animals that have been exposed to other infected animals. Without a traceability system it is more difficult to identify exposed animals and more extensive animal culling is necessary that could decimate herds and most likely destroy many animals that were not exposed. Traceability is also important to assure trading partners that disease outbreaks can quickly be contained and eliminated, opening up the possibility of allowing exports to continue from disease-free regions should international trade rules permit regionalization.

The following sections will discuss the status of traceability systems in Canada and the US.

[9] http://www.inspection.gc.ca/english/anima/heasan/disemala/comp/compense.shtml

1.2.1 United States

In the United States animal traceability has been met with resistance. In 2002 a voluntary plan for animal traceability known as the US Animal Identification Plan (USAIP) was proposed by the National Institute for Animal Agriculture (NIAA). Later renamed the National Animal Identification System (NAIS), it was put in place as a voluntary federal program that would be administered by the Animal and Plant Health Inspection Service (APHIS). Through the program an animal's premise and identity would be recorded and their movements tracked. In addition, the program would monitor vaccination programs, keep track of infected and non-infected regions during a disease outbreak, provide up-to-date animal movement information and set up animal health inspection and certification programs. The program was ultimately scrapped in 2010 due to the resistance of industry and some policy makers who had numerous concerns including costs of implementation, privacy and timely reporting of accurate animal movement data (Schroeder and Tonsor, 2012). A recent study has shown that the benefits accrued from increased animal exports would offset much of the costs of implementing an animal traceability program (Brester et al., 2011).

Due to the failure of the previous program a new mandatory program is being developed that will only be used to track and identify animals that cross state borders. Animals that stay within a state will not be tracked. The USDA is going to phase in the program gradually with full implementation in place for all cattle by 2015 (Schroeder and Tonsor, 2012).

1.2.2 Canada

In Canada, cattle traceability is overseen by the Canadian Cattle Identification Agency (CCIA) which was founded in 1998. The non-profit organization was formed "to promote and protect animal health and food safety concerns in the Canadian cattle herd."(Canadian Cattle Identification Agency, 2009). The traceability program is called the Canadian Cattle Identification Program (CCIP) and is described as "an industry initiated and established trace back system designed for the containment and eradication of animal disease" (Canadian Cattle Identification Agency, 2009). This electronic technology provides timely data on animal movement and traceback information. Data for animals is stored in a database system called the Canadian Livestock Tracking System (CLTS) which is maintained and administered by the CCIA.

Carlberg (2010) discusses the history and recent status of animal identification efforts in Canada. The IDing of dairy and beef cattle via the CCIA is mandatory in Canada as of 2002 and enforced through the CFIA. IDs are implemented by attaching a tag with a unique, registered identification number to the animal's ear soon after it is born. Some provincial governments (Alberta and Québec) have stricter conditions for ID's than the national standards. In Québec, Agri-Traçabilité Québec (ATQ) was the organization formed to develop an ID and traceability system for cattle, sheep and pigs. The ATQ developed and maintains a database of every single animal in the province, covering various species. Producers supply animal information soon after the animal is born (gender, birth date, birth place) and this information is associated to the animal by a tag affixed to its ear. When the animal moves to a different location, its tag is scanned and the movement information is stored in the database creating a log of all movements. Over the animal's lifetime a complete record of where the animal travelled will be stored. Alberta also has a rigorous system that transcends the country's mandatory requirements. Regulations were introduced to move the province to a system that tracks animal ID, premise ID and animal movements. Producers must keep detailed records of their animal inventories including the animal's birth date and species. Owners of facilities where animals will be living must be registered and any animals that enter their sites must be recorded (Carlberg, 2010).

The three pillars of the CCIA system are animal ID, premises ID and movement tracking. As of this writing, premises ID and animal movement tracking are optional. Age verification is also optional except in Alberta, where it is mandatory.[10] The CCIA reports that work is being done to have premises ID fully implemented by December 31, 2013 and to have animal movement tracking at required sites in place by Jan 1, 2016 (Canadian Cattle Identification Agency, 2012).

Most recently the Canadian federal government issued a news release announcing funding to help develop a national livestock traceability system (Agriculture and Agri-Food Canada, 2012g). The Canadian Agri-Traceability Services (CATS) system will combine the efforts of the CCIA and Agri-Traçabilité Québec (ATQ) in order to reduce costs and simplify the recording process.[11] The government pledged $500,000 for building the system and $265,000 to help the two organizations streamline and improve their data management capabilities.

[10] Based on discussion with Kathy Larson (MSc, PAg) who obtained this information from the CCIA.
[11] Presumably also so that there is one national system.

The existence of a cattle identification and traceability program in Canada provides a backdrop to the scenarios developed in the analytical chapter of this thesis.

1.3 Regionalization Policy

During a highly infectious livestock disease outbreak such as FMD, Canada's trading partners would normally halt trade completely for the entire country. If there was a way to assure the trading partners that a disease could be contained then trade could potentially be allowed from disease-free regions of the country. This has been referred to previously as "Regionalization Policy". Under the Uruguay Round Agreement of the WTO, regionalization was explicitly allowed for the first time.

Having an effective traceability system in place is a key assumption for regionalization. This could be achieved by requiring trucking companies to record and report all movements of animals. Another option would be to inspect all animal movements at specific points. There is an area in Canada where geography provides a natural barrier and there is only a single roadway to monitor. The area is called West Hawk Lake (WHL) and will be discussed in the following section.

1.3.1 West Hawk Lake Zoning Initiative (WHLZI)

West Hawk Lake is located in the Whiteshell Provincial Park in southeastern Manitoba, Canada (Figure 1.1). The area is part of the Canadian Shield which is heavily forested and rocky, providing a natural barrier to animal movement. The single roadway connecting western Canada to central Canada is the Trans-Canada highway. These conditions provide an ideal location to effectively monitor animal movements. There would be no way to transport an animal east or west except along this roadway. For this reason, West Hawk Lake has been the focus of attention as a possible means to control the spread of livestock disease.

Located in this area along the Trans-Canada highway is a monitoring station that collects information from producers that are transporting animals (Figure 1.2). The information gathered includes the date of departure and the destination of the animals. The information is recorded in a database and would only be accessed in the case of an emergency. Producer participation is currently on a voluntary basis.

WHLZI is managed by the Canadian Animal Health Coalition (CAHC). The CAHC is described as "a

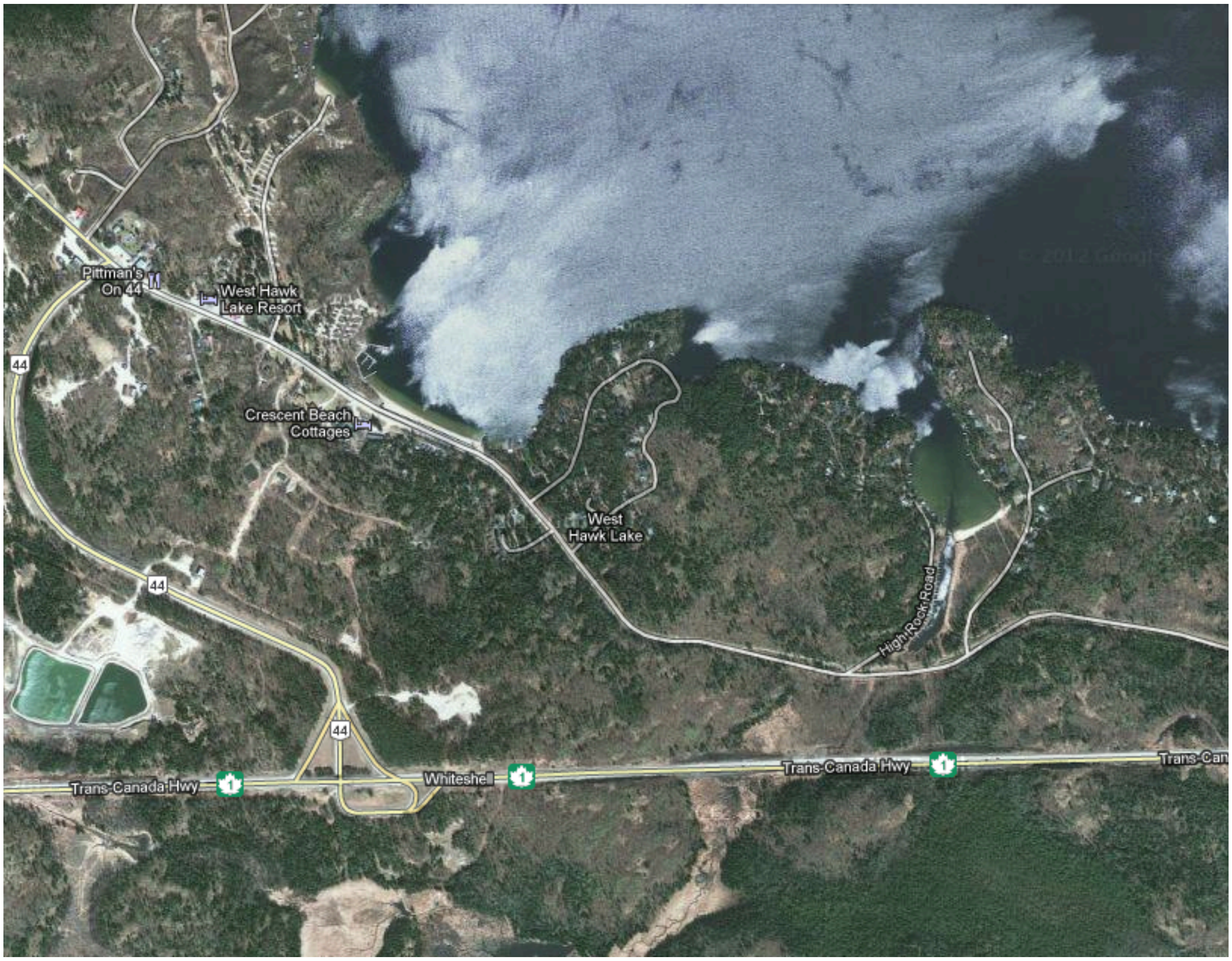


Figure 1.1: West Hawk Lake - Manitoba, Canada.
Retrieved on March 13 2013 from website https://maps.google.ca

Figure 1.2: Trans Canada Highway and WHL Monitoring Station.
Retrieved on March 13 2013 from website http://www.zonecanada.ca

project based organization addressing issues of concern to industry and government through projects funded by industry and government." It is funded through a partnership with the Canadian Industry Traceability Infrastructure Component of the Canadian Integrated Food Safety Program and the Canadian livestock industry. Numerous other organizations provide additional support and direction.[12]

The first phase of the WHLZI involved creating and testing the data system and setting up procedures for collecting data from producers transporting animals. WHLZI completed the first phase of testing in March 2009. Moving forward the CAHC set forth the following objectives for the next phase of the project (Canadian Animal Health Coalition, 2010):

- 24/7 - 365 days operations including client support through the call centre and site activity,
- Confirm funding commitment by industry organizations,
- Enhance producer participation,
- Validate data collection and integrity and assess ease of access of the system,
- Define West Hawk Lake Zoning's role in the National Agriculture and Food Traceability System, and
- Investigate an expanded WHL scope to include other agri-food commodities.

CAHC also established a dedicated website to increase awareness of WHL and help educate the public (www.zonecanada.ca). The website provides information about zoning and the WHL facility. Links to a quarterly newsletter as well as other industries are also found on the site.

Funding for the current phase of the project expired on March 31, 2013. As of Feb 25 the WHL site has ceased operations until new funding can be secured (Canadian Animal Health Coalition, 2013).

WHL is relevant to this thesis because it represents a real world example of a way to physically monitor and prevent the movement of animals in the event of a disease outbreak. As such, WHL will be the basis of one of the scenarios being examined.

[12]Source. CAHC Website: http://www.animalhealth.ca/AboutCAHC.aspx (Accessed March 6, 2013)

1.4 Research Question

This thesis examines the impacts on Canadian livestock (beef) producers and consumers in the event of a Foot & Mouth Disease (FMD) outbreak. It will look at a variety of scenarios ranging from trade being completely halted to trade being allowed from portions of the country through a regionalization policy and through animal traceability.

1.4.1 Methodology

The effects of an FMD outbreak will be measured by calculating the economic surplus in each scenario being examined and comparing it to the base case in which there is no FMD outbreak present. This will show the direction and magnitude of change. If surplus increases then one is better off and vice versa.

The economic surplus measures will be Consumer Surplus (CS) and Producer Surplus (PS). CS is defined as the the difference in the amount of money a consumer is willing to pay for a good and the price the good actually sells for. PS is the difference in the amount a good sells for and the minimum price a producer is willing to sell it for (Perloff, 2012). Total Surplus (TS) is the sum of CS and PS.

Graphically this can be shown with a supply/demand curve for a good and a price. A market demand curve for a good shows the quantity of a good that consumers would want to purchase at every price. The market supply curve shows the quantity that producers would provide of that same good at every price. Figure 1.3 provides an example. *Panel A* shows the supply and demand curve for a good. The good is sold at the equilibrium price where supply and demand intersect. This intersection shows the price the good is sold for P_E and the quantity produced and consumed of the good is Q_E. The light-grey shaded area beneath the demand curve and the price line is the Consumer Surplus region labelled *CS*. The dark-grey shaded area beneath the price line and above the supply curve is the Producer Surplus region labelled *PS*. $CS + PS$ is the total welfare or Total Surplus. This is the base case against which the impacts of change will be measured against.

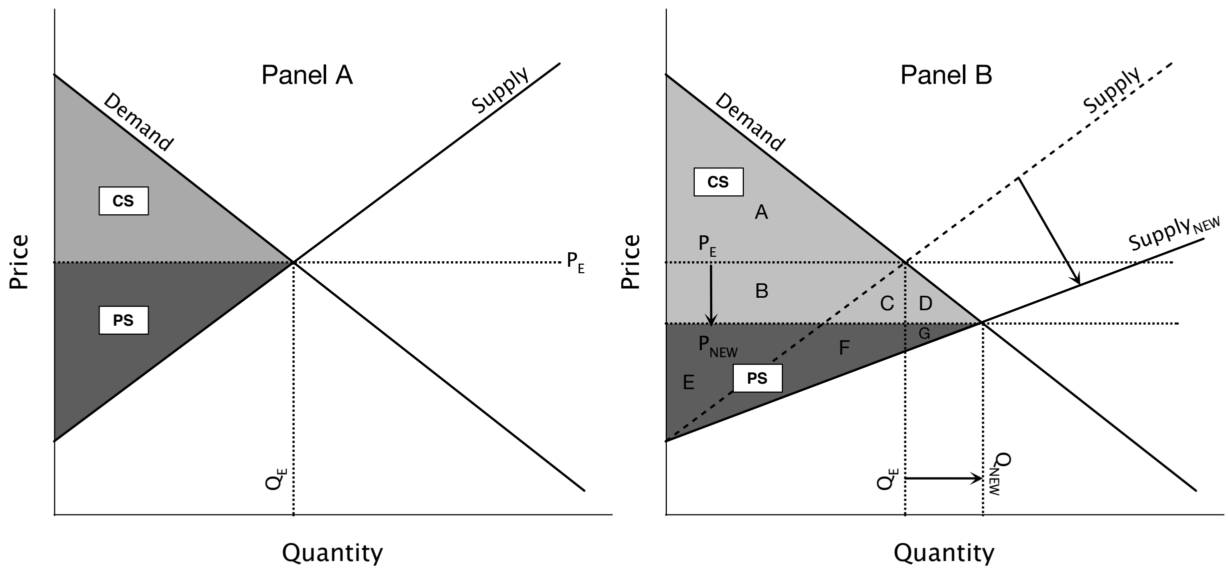


Figure 1.3: Surplus Example

Now look at *Panel B*. An event occurs that causes the supply curve to shift to Supply_{NEW}. We will assume the demand curve remains constant. As a result of the shift in supply, price moves to the new equilibrium price P_{NEW} corresponding to the equilibrium quantity Q_{NEW}. The impact to the consumers and producers due to the change in supply can be measured by calculating the new CS and PS and comparing the new values to the old ones (*Panel A*). By inspecting the graph on *Panel B* it can be seen that CS increases. The previous CS was the area of the triangle A and the new CS is $A + B + C + D$. The difference is $B + C + D$. CS has increased as a result of the supply shift, making consumers better off. The change in PS is a bit harder to measure by visual inspection. The previous PS was the area of the triangles $B + E$. The new PS is $E + F + G$. PS decreases by area B but also increases by area $F + G$. The Total Surplus (TS) is simply the area of all the triangles between the supply and demand curves. It can be seen that TS increases in *Panel B* by $C + D + F + G$ which indicates the overall surplus increased as a result in the shift in supply. By calculating these areas with actual price and quantity data the areas can be determined and then comparisons can be made to see if CS, PS and TS increase or decrease.

This same methodology will be used to evaluate CS, PS and TS for each scenario to compare to a base case. Supply and demand curves will be calculated for livestock production in Canada and the Rest of the World using 2010 data sources. The base case and each scenario will have a set of supply and demand curves in order to measure the direction and magnitude of change in CS, PS and TS.

The scenarios being examined are as follows:

- Scenario 1: An FMD outbreak occurs in Canada and trade is completely shut down.
- Scenario 2: An FMD outbreak occurs in western Canada but trade is allowed from eastern Canada only.
- Scenario 3a: A large FMD outbreak occurs in western Canada but trade is allowed from eastern Canada and the non-infected areas of western Canada
- Scenario 3a: A small FMD outbreak occurs in western Canada but trade is allowed from eastern Canada and the non-infected areas of western Canada

1.5 Layout of this Thesis

Chapter 2 begins with a literature review on past livestock disease studies. It then moves on to the subject of economic models that have been employed in the study of livestock disease. The chapter concludes with a discussion of what is missing from the literature and what can be added.

Chapter 3 discusses the theoretical model that will be used to measure the impacts of an FMD outbreak and the various scenarios that will be examined.

Chapter 4 presents the empirical analysis applied to the theoretical model. Producer and consumer surplus values are calculated for the Base Case and all other scenarios. Assumptions underlying each scenario are also discussed. The chapter concludes with a summary of welfare changes from the Base Case to all scenarios.

Chapter 5 reviews the research question and discusses the results from chapter 4. This is followed by conclusions and suggested policy responses. The chapter concludes with suggestions for further research.

Chapter 2

Literature Review

This chapter begins with a review of previous research on the topic of livestock disease. This leads to a discussion of why livestock disease should be examined as an economic problem. This is followed by examples of different types of economic models that have been used to study livestock disease. The chapter concludes with a short discussion of the selected economic model that will be used for this thesis.

2.1 Previous Research into Livestock Disease

Pritchett, Thilmany, and Johnson (2005) provide a useful overview of the literature that deals with animal disease and its economic impacts. Table 2.1 summarizes the literature and organizes it by scope and by research questions (Pritchett, Thilmany, and Johnson, 2005).

From this a researcher can review how the current literature is organized, what research questions are addressed and how research is conducted. This can help to determine avenues of new research. For producer level studies the authors state that there are challenges to combining economic models of disease outbreaks with epidemiological models. Epidemiological models alone do not adequately calculate the true costs of disease because they do not measure costs outside of the model.[1] Similarly economic models need to incorporate cost information that would be provided by an epidemiological model.[2] A good integrated model that incorporates the best of both worlds requires a great deal of cross-disciplinary cooperation.[3]

[1]For example, the 2001 FMD outbreak in the UK also resulted in costs to the tourism industry that would not be captured in an epidemiological model.

[2]For example, the costs associated with vaccination and culling of herds in a disease outbreak would typically be reported in an epidemiological model.

[3]A third approach would be to use both an epidemiological model and an economic model. The outputs from the epidemiological model would serve as inputs for the economic model.

Scope of Analysis	Research Objectives	Assessment Methods	Policy Instruments	Research Opportunity
Producer Impacts	Business Loss, Incentives for Control	Budgeting, Stochastic Simulation	Compensation, Testing	Epidemiological and Economic Models, Catastrophic Insurance
Allied Agribusiness Processors Suppliers and Supporting Activities	Lost Shareholder Wealth, Business Loss	Efficiency Analysis, Event Analysis	Production Practices, Certification, Traceability	Economic Geography, Market Structure
Consumer	Welfare Loss, Risk Assessment	Partial Equilibrium, CVM, WTP	Education, Certification, Information	WTP/WTA Assessment, Cross Species Substitution
Sector	Industry Losses	Simulation, Efficiency Estimation	Traceability, Certification	Post Harvest Models, Dynamic Models, Epidemiological Links, Market Structure, Distribution
Regional	Welfare Impact, Industry Specific Loss, Inadvertent Loss	I-O Models, CGE	Travel Restrictions, Compensation, Prescribed Cull	Economic Geography, Linking Economic and Epidemiological, Mitigation and Prevention Costs
National and International	Welfare Impact, Distribution of Loss	Partial Equilibrium, CGE	Regionalization, Rapid Response Plans, National ID, Tariffs/Non Tariffs, Barriers Restrictions	Economic Geography, Distribution of Impacts

Table 2.1: Economics of Animal Disease Typology Matrix.
Source: Pritchett, Thilmany, and Johnson (2005)

Sumner, Bervejillo, and Jarvis (2005) consider the idea that animal disease control can be classified as a Public Good (Sumner, Bervejillo, and Jarvis, 2005).[4] The nature of Public Goods is that they are non-rivalrous and non-excludable. A popular example of a Public Good is national defence. National defence is non-excludable because it protects every single individual in a country. It is non-rivalrous because one individual who enjoys the protection from national defence does not prevent another individual from enjoying it at the same time. Due to these characteristics it is difficult for a firm to profitably provide a public good because no one could be excluded and, hence, could obtain the good at no cost (i.e. free-riders). In these

[4]This is not always the case. The example from the South American FMD outbreak (see below) will demonstrate that livestock disease prevention is not always a Public Good.

types of situations it is often the role of the government to provide the good or to subsidize its provision, although this does not necessarily mean that market solutions do not exist.

The authors use FMD as an example to illustrate their points. For a highly contagious disease like FMD, it is necessary to keep infected animals out of a disease-free region in order to maintain the region's disease-free status. This would involve strict monitoring of borders where infected animals may gain access. The cost of monitoring borders is a function of the length of the border and is not related to the number of animals that are protected. When the borders are protected from infected animals all producers benefit because no farms are excluded from this protection and one farm's benefit from disease protection does not diminish the protection another farm receives. Hence the public good nature of animal disease prevention and the potential for "free-riding". The key here is in how the geographic region is defined, as the following example will show.

The FMD outbreaks in South America in 2000-2001 are used as an example to show the public and private nature of the problem. FMD has been a persistent problem in South America - except for Chile which is physically separated from the other southern countries by the Andes. Argentina, Uruguay, Paraguay, as well as southern Brazil decided to try and eradicate FMD from their herds in an attempt to gain access to the profitable world export market. Through extensive vaccination the countries were able to eliminate FMD and eventually wean themselves off vaccination to achieve "FMD free without vaccination" status in April 2000. Unfortunately FMD was still present in Bolivia and northern Brazil and border controls were not sufficient to prevent infected animals from crossing into disease-free regions. Argentinian cattle had higher export prices due to their disease-free status which lured producers to move their animals from other regions with lower livestock prices - in effect smuggling. Without tight border controls and traceability systems there was no way to keep infected animals out. As a result, FMD spread rapidly throughout all the formerly disease-free regions.

The lessons from South America show that eradication of FMD requires 100% compliance from all countries. Contagious diseases can easily pass through administrative borders so it is more useful to plan regionally where the disease is likely to spread rather than focus on administrative boundaries. As long as the economic incentive to "smuggle" exists, stricter border controls are necessary to prevent unauthorized transport of animals by producers (or others) in search of higher prices. In addition, disease-free countries need to cooperate and help their neighbours with their disease eradication efforts, otherwise the disease is likely to return.

Kerr, Loppacher, and Barichello (2009) discuss the subject of "regionalization" in which an exporting country experiencing a livestock disease outbreak may still export product from regions that are proven disease-free (Kerr, Loppacher, and Barichello, 2009). In the past a livestock disease outbreak would usually result in the entire country being banned from exporting product to other countries. This country-wide ban could cause economic hardship which could take years to overcome. To mitigate this the WTO members agreed on a provision to allow exports from disease-free regions in their 1995 Agreement on The Application of Sanitary and Phytosanitary (SPS) Measures. SPS refers to a set of policies that deal with the international trade of anything that can spread disease including plants, animals and food. Although an importing country has a strong incentive to keep a disease out, it should not use this as an excuse to unnecessarily prevent imports in order to provide economic protection for its domestic producers. The 1995 agreement states that governments should implement the least trade-restrictive policies that ensure protection from disease. A violation of this provision of the SPS could result in retaliation via the WTO dispute settlement mechanism. The challenge to policy makers is to examine the topic of regionalization from an economics perspective instead of merely from a scientific one. In the event of a livestock disease outbreak and the creation of disease-free zones, exporters from a disease-free zone will not face the restrictions that producers in the affected zone face. As a result, there will be the temptation for producers (or others) to smuggle their products to the disease-free zone in order to achieve the advantages producers in that area enjoy. Smuggling livestock runs the risk of further spreading the disease until no disease-free zones remain. Policy makers need to create policies that will adequately compensate producers in the affected zone and, thus, eliminate the incentive to smuggle. Kerr, Loppacher, and Barichello (2009) illustrate a number of scenarios and associated costs through the use of a multi-market partial-equilibrium model.

A more detailed paper on the subject of regionalization by the same authors cite Canada as an example of where regionalization is being explored (Loppacher, Kerr, and Barichello, 2006). The Canadian Shield serves as a natural barrier between eastern and western Canada and, hence, if a livestock disease outbreak occurred in either region it would be feasible to monitor animal movements from West Hawk Lake which serves as a single connection point between east and west.

Junker, Komorowska, and van Tongeren (2009) developed some case studies that looked at costs related to trade bans due to FMD outbreaks. They looked at the US, Canada and the Netherlands using scenarios of control that included stamping-out or vaccination combined with a regionalization policy. With regards to regionalization, the authors found that the costs of implementation were well below the gains that were made and that it reduced the opportunity costs that come from trade restrictions. Furthermore they found that Canada, being a net exporter of beef, did not gain much from regionalization (Junker, Komorowska, and van Tongeren, 2009).

A potential livestock disease outbreak involves a number of procedures at different stages. There are procedures to *prevent* the onset of disease, procedures to *monitor* the onset of disease and procedures to *control* and *eradicate* disease once an outbreak has occurred. Producers and other stakeholders may partake in procedures in any of the three stages. Researchers used an Avian Influenza (AI) outbreak to model optimal levels of activities in each of the three stages (Longworth et al., 2008). They wanted to see what the optimal levels of activities would be when different objective functions were maximized: human health, government cost, producer profit or consumer utility. The authors developed a series of functional forms which were optimized using data based on AI outbreaks in the Netherlands. Their results are reproduced in Table 2.2 with bolded numbers being the best achievable results and italicized numbers being the worst achievable results.

Obj.	Health[a]	Cost[b]	Profit[c]	Utility[d]	X^P	X^M	X^C
Health	**0.05**	14.00	*133.71*	**150.24**	100	100	34
Cost	1.53	**10.32**	153.92	149.34	75	85	25
Profit	*1.61*	*603.25*	**206.16**	*149.35*	0	42	100
Utility	**0.05**	14.00	*133.71*	**150.24**	100	100	34

[a] Annual expected number of human infections with AI virus
[b] Annual expected cost for the government, in million €
[c] Annual expected profit for a representative producer, in thousand €
[d] Annual expected utility for a representative consumer, in utils

Table 2.2: Payoff matrix for the four objectives when prices do not change
Source: Longworth et al. (2008)

The results show that when Health or Utility are the objectives, prevention X^P and monitoring X^M efforts will be maximized resulting in the highest results for Utility and Health. Minimizing Cost will require less than full efforts in prevention and monitoring (75 and 85 respectively). If maximizing Profit is the objective than 0 resources will be used in prevention, 42 for monitoring and 100 for control. Maximizing profits yields the worst achievable values for health, cost and utility whereas maximizing Health and Utility yield the lowest profits. When profits are not the primary objective, the results show that prevention and monitoring are the dominant strategies.

2.2 Livestock Disease as an Economics Problem

McInerney (1996) argues that livestock disease is really an economics problem. In Figure 2.1 he shows the system of livestock production from the producer to the consumer and how disease affects all parts of the system. Each dashed line shows what effect disease can have at that point in the production system (McInerney, 1996).

The author claims that previous research into livestock disease, conducted primarily by veterinarians, does not provide useful disease information (McInerney, 1996). The cost estimates are usually just one component of the effects of a disease outbreak, such as the costs of culling livestock, costs of vaccination, costs of setting up quarantine zones, etc. These costs, however, underestimate the true cost of an outbreak because they do not include the costs arising from externalities. Such externalities could be lost income due to restricted access to export markets or losses to businesses that operate inside a quarantine zone or even reduced demand by consumers due to a change in preferences. All of these costs are directly related to livestock disease.

According to McInerney (1996), the shortcoming of past research is that it focusses on the production side of livestock. This gives the impression that farmers are the only ones affected by livestock disease through loss of profits. Figure 2.1 shows that disease affects the entire food-chain and therefore is a problem which affects society more broadly. His solution is to model livestock as a regular production function (see Figure 2.2). As more resources are put into production, production increases and eventually levels off from decreasing returns to scale. With livestock disease the production function shifts downwards at all levels because the resource inputs yield smaller outputs as compared to a healthy animal. R_O represents the resource inputs of a small livestock operation and R_D is a larger operation. As Figure 2.2 shows, the larger livestock operation loses a higher amount of output as a result of disease (CD) than the smaller operation (AB).

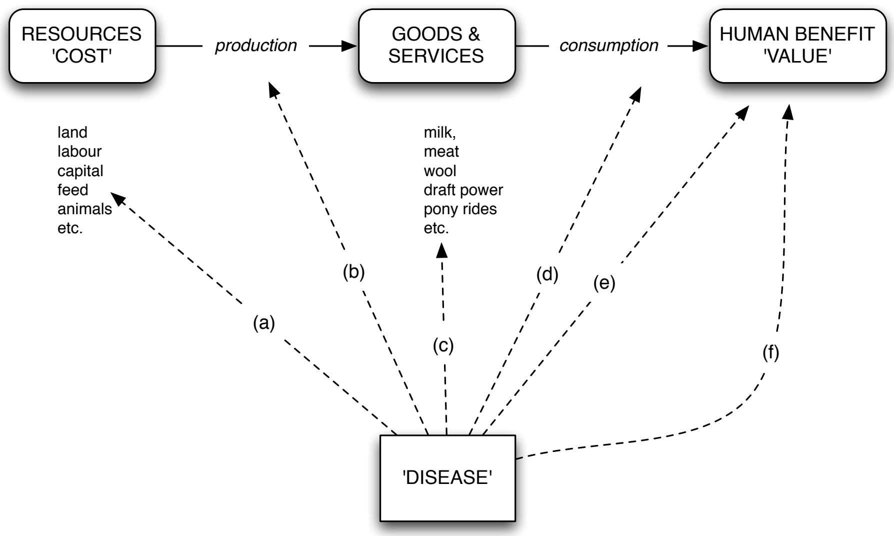


Figure 2.1: Disease in the Livestock Production System.
Source: McInerney (1996)

(a) destroys the basic resources (mortality of breeding or productive animals)

(b) lowers the efficiency of the production process and the productivity of resources used (reduced rates of growth or feed conversion)

(c) reduces the realized physical output of the production process or its unit value (lowered milk yield or quality)

(d) lowers the suitability of livestock products for processing, or generates additional costs in the distribution chain (drug residues, meat inspection)

(e) affects human well-being directly (zoonoses such as salmonella and brucellosis)

(f) an array of more diffuse negative economic effects which reduce the total value a society gains from its livestock (e.g. constraints on trade, change in consumer preferences, etc.) as well as externality effects in unrelated industries (e.g. diminished revenue as a result of the decrease in tourism due to quarantine zones established to control a disease outbreak)

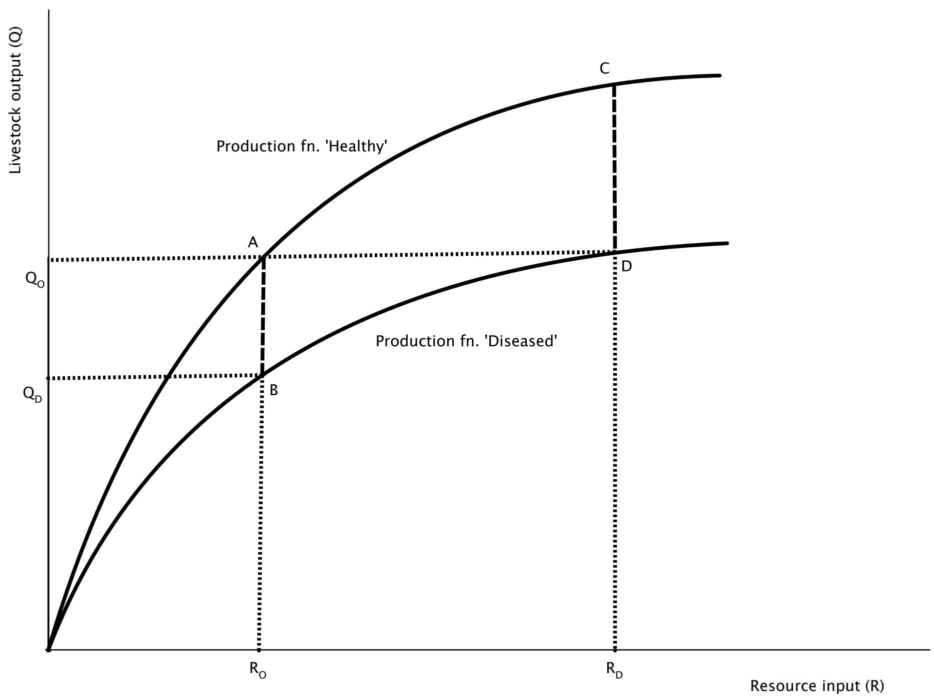


Figure 2.2: Disease Effects on the Livestock Production Function.

Source: McInerney (1996)

Figure 2.3 from McInerney (1996) shows where a profit maximizing producer would operate with healthy livestock and the adjustments to inputs and outputs in the presence of disease. With healthy livestock the producer would produce at the level where the production function is tangent to the line which represents the ratio of input prices (P_R) and output prices (P_Q). Mathematically this is represented by Equation 2.1. This profit maximizing point is represented by point E on the figure with resource input of R_O yielding an output of Q_O. The presence of livestock disease yields lower output at all levels of input (represented by the lower curve on the figure). The profit maximizing producer would then operate at point K with input level R_D° yielding output Q_D°. Point K is found by shifting down the price ratio curve until it intersects the diseased livestock production function.

$$\frac{\partial Q}{\partial R} = \frac{P_R}{P_Q} \tag{2.1}$$

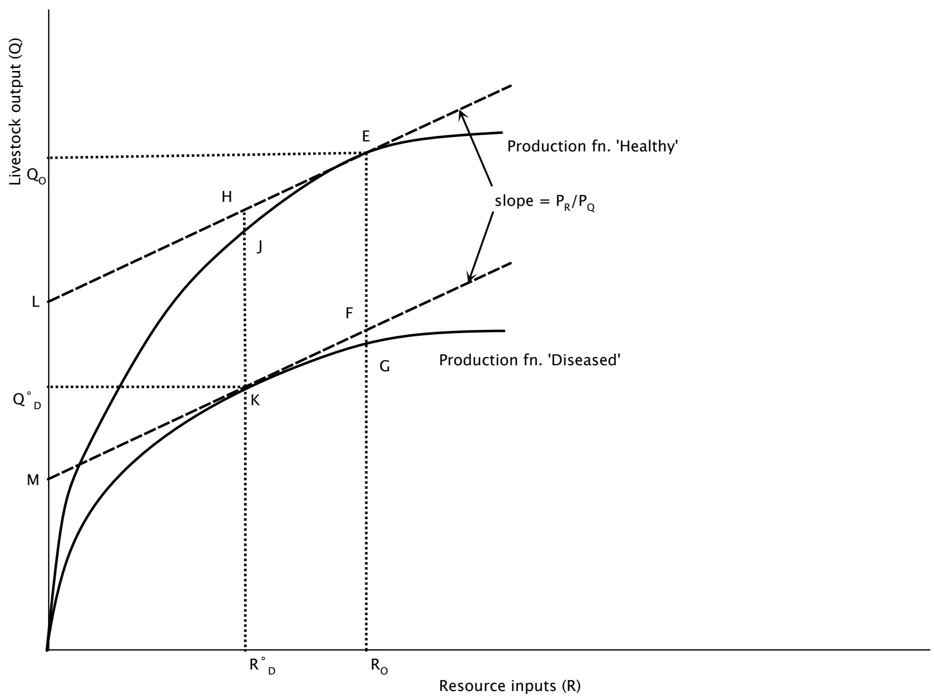


Figure 2.3: Economic Adjustments and the Cost of Disease.

Source: McInerney (1996)

McInerney goes on to say that economists need to frame the problem from a veterinarian's perspective rather than from an economist's perspective since ultimately veterinarians will be deciding on a course of action in the face of a disease outbreak. An appropriate method is to frame the problem using a "loss-expenditure frontier". This starts by defining the costs of the disease (C). Specifically $C = L + E$ where L represents *loss* due to disease (lower output, death of livestock, reduced productivity, etc) and E represents *expenditures* used to control the disease (veterinary services, vaccines, etc). By distinguishing loss from expenditures it shows that these are separate components to the total cost of disease and that one can be substituted for the other. It also makes clear that the goal of the problem is to minimize costs.

Figure 2.4 from McInerney (1996) illustrates the loss-expenditure frontier. If no money is spent on control expenditures E then losses will be maximized at point L'. As money is spent on control expenditures, losses L will decrease at a decreasing rate through diminishing marginal returns. The line $L' - L''$ shows the lowest losses attainable for each combination of E and L. We assume in this example that disease elimination is not possible no matter how much is spent on control expenditures. If the disease we were looking at could be completely eliminated then the curve would eventually intersect the x-axis.

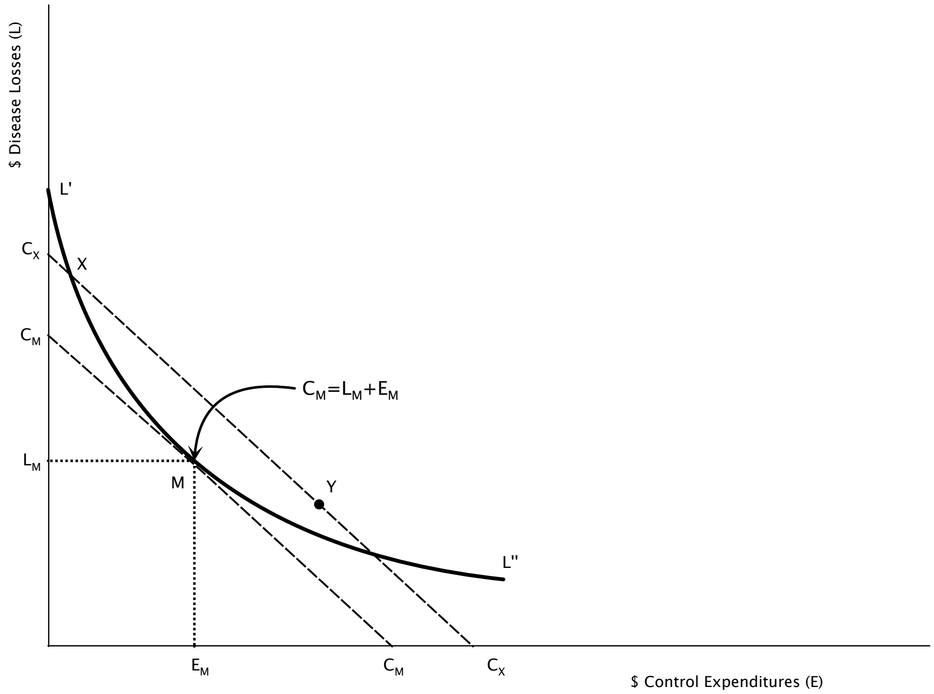


Figure 2.4: The Disease Loss-Expenditure Frontier.
Source: McInerney (1996)

Line C_X is an isocost line that shows all combinations of E and L which total to the same cost, C. Therefore the total cost at point X and point Y would be the same. Operating at a cost above the curve $L' - L''$ is possible (point Y) but inefficient and more importantly it is avoidable. Operating at a point below curve $L' - L''$ is not possible. Point M is the intersection of curve $L' - L''$ and isocost line C_M. This point represents the minimum cost attainable for disease control where an expenditure of E_M will result in a loss of L_M. This conclusion could be troubling to veterinarians because it admits that there is an acceptable level of disease that differs from the total elimination of disease. The diagram also shows that while spending more on control expenditures would lower disease losses, the savings would be offset by higher control expenditures and consequently a higher total cost C.

This example can be applied to FMD prevention. If Canada did not spend any money on FMD prevention there would be dire consequences if an outbreak occurred. An FMD outbreak would spread rapidly with no way to monitor animal movements through traceability and no vaccinations to administer to control the spread of disease. Borders would close to livestock trade from the entire country because there would be no way to assure trading partners that the disease is under control. The only way to eliminate the outbreak would be massive culls of animals. The savings from not expending resources on FMD control would most likely be far exceeded by the losses due to disease outbreak. The 2001 FMD outbreak in the UK resulted in more than £13 billion in losses, taking into account compensation costs and losses to tourism. On the other hand, if Canada spent billions of dollars on FMD control through traceability systems and vaccination development there would still be a possibility that an outbreak could occur. Vaccinations are not 100% effective against the disease and must be tailored to a specific strain. Past outbreaks in other countries have occurred through contaminated meat entering the country which would be very difficult and costly to totally eliminate. The best approach would be a balanced one that prepares for the possibility that an FMD outbreak could occur and when it does to take care of it quickly.

In his 1996 article, McInerney borrows from his earlier work in which he first introduces the concept of the *loss-expenditure frontier* as a way to frame the idea of livestock disease in an economic setting (McInerney, Howe, and Schepers, 1992). In their 1992 work the problem is described a bit differently but uses the same diagrams. They discuss the concepts of marginal benefits and marginal costs and that the optimal amount to spend on disease control is the point where one dollar spent on control yields one dollar of benefit.

McInerney (1996) made a strong case that livestock disease is an economics problem and prepared the groundwork for future researchers to address this shortcoming in the literature. The next section provides a more detailed examination of models used to examine the economic impact of livestock disease.

2.3 Overview of Economic models

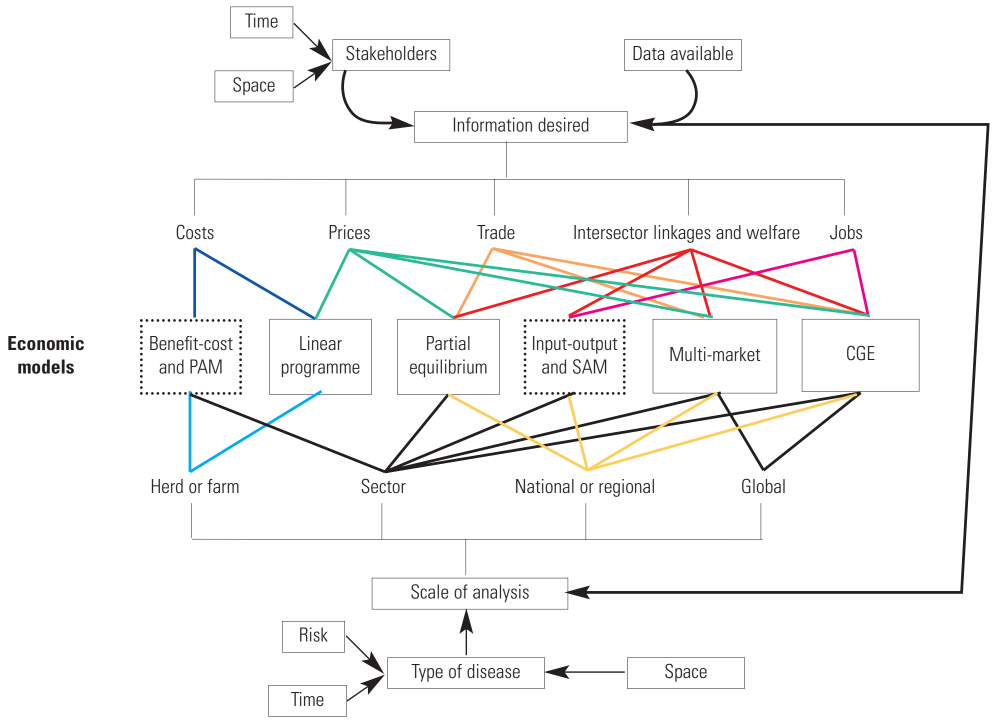
Rich, Miller, and Winter-Nelson (2005) discuss various methods to study livestock disease which combine an epidemiological model with an economic model. Their model shows the number of animals culled and/or vaccinated as a result of an outbreak. The economic model shows the costs as a result of the outbreak. (Rich, Miller, and Winter-Nelson, 2005). They argue that in the current literature economic modelling was being under-utilized in the study of livestock disease. Their article summarizes the relevant models that apply to livestock disease and their suitability. A companion paper by the same authors offers suggestions on how to enhance the economic models to make them more effective as well as ways to combine different models to further increase their effectiveness (Winter-Nelson, Rich, and Miller, 2005).

The research questions being asked will determine the appropriate economic model to use as there is no single model that is appropriate for all situations. The scale of the question is also important in selecting the appropriate model. The scale can range from very small (herd level) to very large (global market). Table 2.3 lists popular research questions and examples relevant to livestock disease.

Research Question	**Example**
Costs	What are the costs that producers and consumers face as the result of a livestock disease outbreak?
Prices	How are producers and consumers affected by changing prices of meat products as a result of a livestock disease outbreak?
International Trade	Many countries do not import meat products from countries that have livestock disease. How would a change in demand affect prices?
National Welfare	A livestock disease outbreak can affect other industries along the supply chain as well as industries not directly connected. For example, the 2001 FMD outbreak in the UK affected tourism when quarantine zones were established.
Employment	How would a livestock disease outbreak affect jobs in the sector?

Table 2.3: Research questions asked of livestock disease economic models
Source: Rich, Miller, and Winter-Nelson (2005)

Figure 2.5 summarizes the various economic questions and scales from which an appropriate model can be chosen. The following sections expand on the economic models shown in Figure 2.5 by giving an overview of the model, the suitable research questions the model can answer, references to applied research that utilized the model and the pros and cons of using the model.



CGE: computable general equilibrium model

PAM: policy analysis matrix

SAM: social accounting matrix

Figure 2.5: Typology of economic models for animal disease analysis.

Source: Winter-Nelson, Rich, and Miller (2005)

2.3.1 Cost-Benefit Analysis (CBA)

Application

Cost-benefit Analysis (CBA) is used to calculate the costs and benefits of a disease event in order to see the net benefits.[5] CBA data comes from the budgets of activities. In terms of a livestock disease outbreak, CBA can be used to see how profits change as a result of different outcomes from the outbreak. Results can be standardized into meaningful units such as net present value (NPV), cost-benefit ratio (CBR) or internal rate of return (IRR).

[5]Of course net benefits can be positive or negative.

Suitable Research questions and scale

CBA is suitable for research questions that deal with costs at the herd/farm and sector levels. The data is based on fixed budget figures which do not vary over time with market conditions or because of consumer behaviour. This makes CBA more suitable for short-term analysis because the data does not change as a result of market conditions.

Pros/cons

CBA can be combined with epidemiological models in order to examine the short-run effects of a livestock disease outbreak. CBA is less useful for determining long-run effects due to the fact that it relies on fixed budgets which normally would change over time due to market conditions or consumer behaviour. CBA is also not well suited for looking at spillover effects into other industries.

References to Applied research

Bates, Carpenter, and Thurmond (2003) examined the merits of vaccination and preemptive herd slaughter to control FMD using CBA. They used the direct costs for disease control, indemnity and post-disease activities (cleaning and disinfection). CBA was used to determine a cost-benefit ratio in order to determine the effectiveness of each strategy (Bates, Carpenter, and Thurmond, 2003). Disney et al. (2001) use CBA to determine the economic benefits of an improved animal traceback system when dealing with a foreign animal disease. Costs used in their model include direct costs of an outbreak as well as the costs of surveillance, slaughtering and vaccination. They also try to capture the indirect costs due to trade loss by estimating the decreased number of animals to be exported. The analysis does not take into account the fact that animals that are not exported are added to the domestic market (Disney et al., 2001). Randolph et al. (2002) utilize CBA to examine the economic impacts of FMD control and eradication in The Philippines where the disease has been prevalent since it was introduced to the country in 1902 from imported animals. The costs of various eradication scenarios are compared to the expected benefits realized from the eradication of disease (Randolph et al., 2002).

Enhancements

A Policy analysis matrix (PAM) is a series of budgets that show the costs and revenues along each segment of the marketing chain. Used in conjunction with CBA researchers can model the linkages between closely related activities. This approach still would not allow modelling effects in other industries that are less directly linked (e.g. the effects to tourism in the event of livestock disease outbreak) and so it would not be an ideal tool for examining spillover effects. Some work has been done by combining CBA with Input-Output (I-O) models or Computable general equilibrium (CGE) models to overcome the limitations discussed.

2.3.2 Linear Programming Models (LP)

Application

Linear Programming (LP) is used for finding optimal solutions to a minimization or maximization problem subject to constraints, where the constraints are usually levels of inputs and outputs. LP can deal with optimizing multiple constraints covering different farm activities and it can deal with changes to inputs and outputs as a result of market behaviour. This makes LP a suitable tool for long run analysis.

Suitable Research questions and scale

LP is suitable for research questions that deal with costs and prices at the herd/farm level. It has been used to determine costs of various disease prevention policies at the farm and national level.

Pros/cons

LP can be used to optimize multiple farm activities. It is able to optimize the solution based on producer reaction to changes in the marketplace, making it more suitable for long-run analysis. LP has significant data requirements which may be an impediment to its use.

References to Applied research

Koybayasi et al. (2007) used a linear programming approach to evaluate the effectiveness of daily control strategies of slaughter and vaccination used in the presence of FMD in the Central Valley of California. Their model minimizes the total regional cost of an entire FMD outbreak taking into account the dynamic nature of the disease and resource constraints (Koybayasi et al., 2007).

2.3.3 Input-Output (I-O) and Social Accounting models (SAM)

Application

Input-Output (I-O) models capture the flow of inputs and outputs between different entities. For example, the agriculture sector may make purchases (inputs) from other sectors such as forestry, livestock, manufacturing, services, etc. It would also make sales (outputs) to these same sectors. An I-O table would show all of these input and output activities (see Table 2.4). The I-O table can be expanded upon through the use of a Social Accounting Model (SAM) which shows the flow of land/labour/capital to other institutions not indicated on the I-O table. A complete model can be used to show how the various sectors of the economy react to an exogenous shock such as a livestock disease outbreak which changed export demand.

			Purchases from				
Sales to	**Agric.**	**Forestry**	**Livestock**	**Manuf.**	**Services**	**Final Demand**	**Total**
Agric.	200	75	100	30	20	25	450
Forestry	30	20	10	50	40	10	160
Livestock	50	5	50	15	50	30	200
Manuf.	100	25	10	250	50	25	460
Services	20	10	10	25	100	135	300
Value-added	50	25	20	90	40	100	325
Total	**450**	**160**	**200**	**460**	**300**	**325**	**1,895**

Table 2.4: Example of an Input-Output (I-O) table
Source: Rich, Miller, and Winter-Nelson (2005)

Suitable Research questions and scale

I-O/SAM is suitable for research questions that deal with intersector linkages and jobs at the sector or national level. It has been used to find the direct and indirect impacts from different disease scenarios in terms of income and employment.

Pros/cons

The accuracy of an I-O/SAM model depends on the level of aggregation between the various sectors. If a sector is not sufficiently disaggregated then its effects may appear stronger than they actually are. Price changes cannot be incorporated into an I-O/SAM model and so it is not an effective solution for modelling long-term effects in which price changes would naturally occur. Another shortcoming is that the models only work with changes to the demand side and not the supply side. The supply curve is assumed to be perfectly elastic and thus the effects of a shock can be overstated.

References to Applied research

Garner and Lack (1995) used I-O analysis to measure the indirect economic effects of an FMD outbreak in Australia on various industries. They used a transactions table which describes the economy in terms of industry sectors and traces out transactions to these other industries in dollar terms over a 1 year period. This allowed them to calculate the multipliers which shows the effects of disease outbreak output, income and employment for the sectors they were examining (Garner and Lack, 1995). Ekboir (1999) determined the impact of an FMD outbreak in California. An I-O model was used for one component of the analysis to estimate the value of direct, indirect and induced losses. The author used an I-O model developed for the state of California by M.I.G. Incorporated (Ekboir, 1999). Mahul and Durand (2000) utilize an I-O model to estimate indirect losses due to an FMD outbreak in France and developed a series of multipliers for a variety livestock sectors and other sectors of the economy. The authors state that a limitation of using I-O is the use of fixed prices which means that market equilibrium has to be achieved through a change in quantity only and therefore it is not suitable for long-run analysis. They suggest a CGE model would be a more suitable approach as both prices and quantities can adjust in equilibrium (Mahul and Durand, 2000).

Enhancements

The short-run cost outputs of a CBA model can be used as inputs to an I-O model. In this case the I-O model would expand on the limitations of the CBA. The I-O assumption of perfectly elastic supply can be addressed through using mixed-multipliers which allow a supply response.

2.3.4 Computable General Equilibrium (CGE) models

Application

Computable general equilibrium (CGE) models combine parts of Input-Output (I-O) models and Partial Equilibrium Models (PEM) to model a complete economy. PEM is enhanced by adding functions to model elements beyond the scope of regular PEM such as labour, capital, international trade and currency markets. The trade-off for this additional information is that CGE models are more difficult to create and interpretation is more complex. CGE is able to transcend I-O and PEM by being able to capture many types of economic linkage that would not be possible by either modelling technique alone.

Suitable Research questions and scale

CGE is suitable for research questions that examine prices, trade, intersector linkages and welfare and jobs at a sector, national or global level. It has been used to determine the economic impacts of an FMD outbreak on welfare, trade and income.

Pros/cons

CGE relies on I-O tables which can be highly aggregated. Due to the high level of aggregation they may not yield detailed information on certain agriculture sectors. CGE models contain a large amount of information and are more complex than I-O models which may make interpretation of results more difficult.

References to Applied research

Rich (2004) used a epidemiological-economic model called DISCOSEM (DISease COntrol Spatial Epidemiological-economic Model) to analyze FMD in South America. He claims that past studies using PEM have been static or dealt only with short-run analysis which are unsuitable for FMD because in the event of an outbreak there will be changes in both production decisions and input allocations. The DISCOSEM model overcomes these limitations through the use of Mixed Complementary Programming (MCP) which is used in Computable General Equilibrium (CGE) models. The model uses a five-year time span to show changes as the market progresses and models trade flows across the different countries (Rich, 2004). Blake, Sinclair, and Sugiyarto

(2003) developed a CGE model of the UK economy to determine the economic impact of the 2001 FMD outbreak on tourism. The authors' model includes production relationships for 115 sectors of the economy and markets for 115 goods and services as well as data on tourism demand (Blake, Sinclair, and Sugiyarto, 2003).

Enhancements

CBA can be combined with CGE models to provide more detailed activity information. Other than the Rich (2004) paper there has not been very much work done in linking epidemiological models to CGE models.

2.3.5 Partial Equilibrium Models (PEM)

Application

A Partial Equilibrium Model (PEM) is represented by a supply and demand curve for a market showing the equilibrium level of price and quantity. The supply function is a mathematical function that reflects the constraints producers face bringing product to market and the demand function reflects consumer preferences. At the equilibrium price and quantity consumer surplus and producer surplus are maximized as per standard microeconomic theory. Market shocks due to a livestock disease outbreak can result in shifts to the supply curve when output levels have decreased. Similarly changes in consumers preferences as a result of a livestock disease outbreak could result in shifts of the demand curve. When shifts occur the new equilibrium quantities and prices are determined. Welfare economics would indicate that if consumer and/or producer surplus decreases as a result of a livestock disease outbreak then society is worse off. PEM can be used to study multiple sectors using a Multi-market model in order to examine the effects of a shock in other sectors.

Suitable Research questions and scale

PEM is suitable for research questions that deal with prices, trade and national welfare at the sector or regional level. PEM is also suitable for multi-market analysis which would allow examination of the effects of a livestock disease outbreak in other agricultural markets. For example, how would the poultry industry be affected due to a change in consumer preferences as a result of a livestock disease outbreak in another sector?

Pros/cons

PEM is a popular and widely used tool in determining and analyzing agricultural policy. Models have been developed by large organizations such as the USDA and the World Bank. PEM can measure changes in the market due to shifts in supply and demand however, it does not lend itself to determining detailed price and cost information at the farm level such as is possible using CBA. Data requirements can be large for larger models but existing models can be modified where appropriate.

References to Applied research

Schoenbaum and Disney (2003) used PEM to determine the economic consequences of an FMD outbreak under alternate mitigation strategies. They showed the change in consumer surplus and producer surplus resulting from the decrease in supply of cattle due to the culling of animals (Schoenbaum and Disney, 2003). Berentsen, Dijkhuizen, and Oskam (1992) developed an economic model that calculates the direct and indirect costs to producers and government. Direct costs are handled by the "Disease Control Model" and include ring vaccination (i.e. vaccination of all animals inside a set distance) and culling which are itemized into specific categories. Indirect costs are handled by the "Export Model" where changes in prices and quantity of beef as a result of an FMD outbreak are used to calculate consumer surplus and producer surplus (Berentsen, Dijkhuizen, and Oskam, 1992). Paarlberg, Lee, and Seitzinger (2002) used a PEM approach to estimate the impacts on farm revenue in the US in the event of an FMD outbreak. They wanted to capture the effects of quarantining and culling animals as well as an export ban and a change in consumer preferences. Three market effects of an FMD outbreak were simulated: a decrease in domestic supply of animals due to quarantine and culling; the closing of export markets; and a change in consumer demand for beef. The effects were quantified using an empirical partial-equilibrium model (Paarlberg, Lee, and Seitzinger, 2002).

Enhancements

CBA can be used to supply activity costs for a PEM. Multi-market models can widen the scope of analysis by including linkages to other sectors including non-agricultural sectors.

2.3.6 Conclusions

Each of the different modelling techniques have their place in the study of livestock disease. The selection of the appropriate model depends on the types of questions being asked, the availability of data, and the difficulty in creating a suitable model. All the modelling techniques discussed will be enhanced by greater integration with an epidemiological model and inter-disciplinary collaboration.

This thesis uses a Partial Equilibrium Model (PEM) for the study of the trade effects of FMD outbreaks. PEM allows us to evaluate how much better or worse off society would be under different scenarios of disease outbreak and trade restrictions. It can go further by looking at the welfare of consumers and producers separately to see if the benefits of one group come at the expense of the other. For example, when the price of a good goes down consumers are better off because they pay less and have more money for other things. On the other hand, the producers of the good are worse off because they are making less profit from the lower prices. Taken as a whole, however, is society better off or worse off? PEM will allow us to evaluate the outcomes and make conclusions on the benefits to society. We can also compare the magnitude of benefits to rank outcomes in terms of how much better (or worse) one scenario is over another.

The PEM model found in the paper by Kerr, Loppacher, and Barichello (2009) is well suited as the basis upon which the research in this thesis is undertaken (Kerr, Loppacher, and Barichello, 2009). The data that is needed for the model can be obtained through the literature and industry websites, lowering the costs of data collection. The research is focused on impacts at a regional level, an appropriate role for the use of a PEM.

Chapter 3

Theoretical Model

This chapter begins with a discussion of the theoretical model that will be used as the basis for the analysis. This is followed by a discussion on the modifications made to adapt the model to beef markets in Canada and the US. The chapter concludes with a discussion of the different scenarios that will be examined.

3.1 Theoretical Model

A Partial Equilibrium Model will be used to study the impacts on producers[1] and consumers of an FMD outbreak in the context of loss of export market access. The model is based on the one described in "A Trade Regime for Sub-national Exports Under the Agreement on the Application of Sanitary and Phytosanitary Measures" (Loppacher, Kerr, and Barichello, 2006). The model utilizes a three panel diagram to represent supply and demand curves for livestock products in three different regions. In each figure *Panel A* represents the exporting country's infected region; *Panel B* represents the exporting country's non-infected region and *Panel C* represents the rest of world (*ROW*).

Figure 3.1 shows the case where livestock disease is not present. *Panel A* shows the supply and demand curves representing the values for domestic consumption. In the absence of trade, prices will go to their equilibrium value of P_2 where supply equals demand. At any price above P_2 the country will export product. In *Panel B* the demand for livestock products on world markets is represented by the demand curve D_{row}. The supply curve S_{row} shows the supply of product in the rest of the world excluding imports from the country of interest. The equilibrium price on the world market without imports from the country of interest is P_1. At any price below P_1 the *ROW* will import livestock products provided they meet phytosanitary

[1]Producers in this analysis refers to all groups in the beef supply chain (e.g. feedlots, packers, cow-calf, etc.).

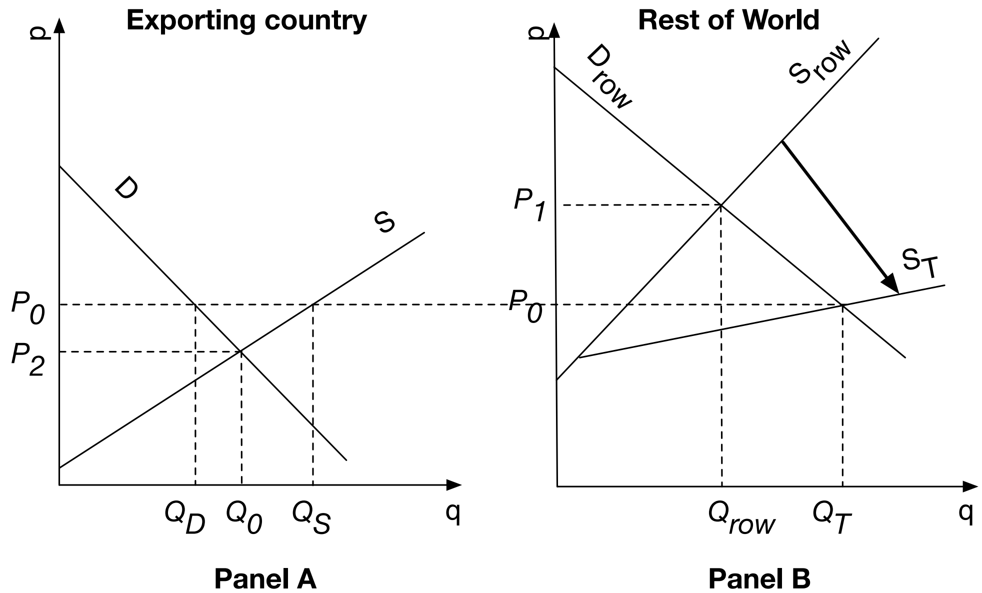


Figure 3.1: Prices and quantities when livestock disease is not present.

requirements. Since P_1 is greater than P_2 the exporting country will export product to the ROW. This will cause the supply curve in the ROW to shift to S_T which represents the total supply to ROW including imports. This shift causes prices to fall to P_0. At price P_0 the exporting country will export and the ROW will import. The exporting country will export the amount $Q_S - Q_D$ where price P_0 intersects the exporting country's supply and demand curves.

Next is the scenario in which livestock disease is detected in the exporting country (Figure 3.2). The exporting country is now represented by two panels. *Panel A* is the infected area and *Panel B* is the non-infected area. Livestock disease is detected in one region of the country and the ROW closes its borders to all imports from that country. This is consistent with the current standard practice in international markets. Supply in ROW shifts back to S_{row} and price increases from P_0 to P_1. In the exporting country that is no longer able to export, prices shift from P_0 to P_2 to supply domestic demand only.[2] Quantities shift accordingly to equilibrium values at the new prices. At the ROW price P_1 the exporting country would be willing to export but the borders are closed until the disease is eliminated.

Next we look at the scenario in which a Regionalization Policy is in effect (Figure 3.3). Under the

[2]We are assuming that the livestock disease is not harmful to humans and that product is safe to sell. This may not be the case for a livestock disease such as BSE.

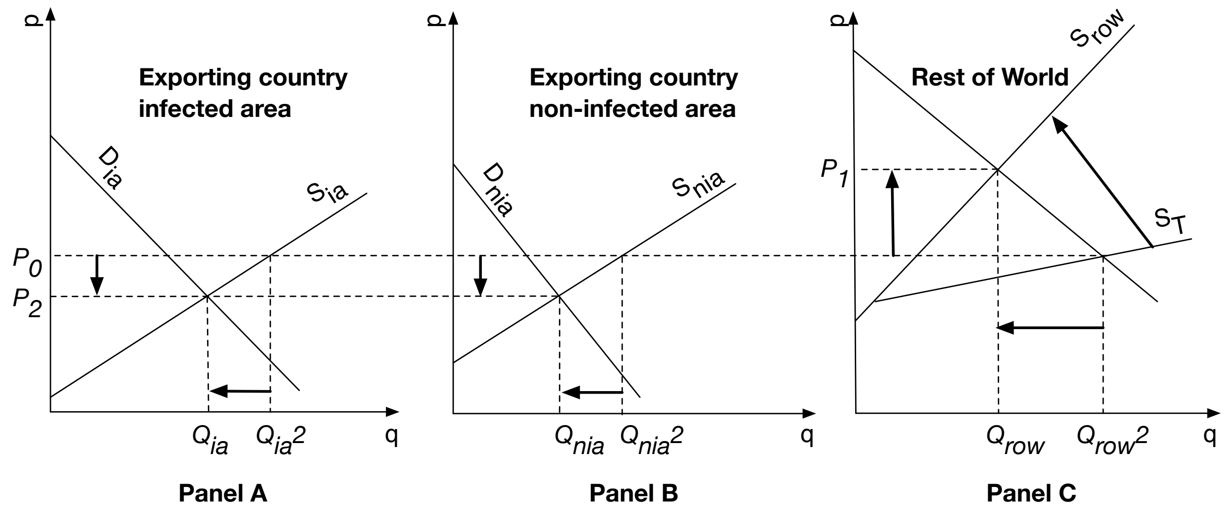


Figure 3.2: Prices and quantities when livestock disease outbreak is present and borders are closed to trade.

Regionalization Policy the *ROW* is willing to import livestock products from the non-infected region of the exporting country only. The exporting country has guaranteed the *ROW* that livestock product in the non-infected area are free of disease due to credible animal traceability and zoning measures having been put into effect. As a result the supply curve in the *ROW* shifts up to $S_{row} + S_{nia}$. Note that the supply curve has not shifted to S_T because only product from the non-infected area is being imported (when compared to a total export ban). Prices at equilibrium in the *ROW* shift from P_1 to P_3 and quantity increases from Q_{row^1} to Q_{row^3}. At price P_3 that the non-infected area now receives, quantity increases from Q_{nia^1} to Q_{nia^3}. At the price P_3 the non-infected area would produce more and export it to the *ROW* indicated on *Panel B* by 'Exports' (the difference between supply and demand at price P_3). Price P_3 that the non-infected area receives is higher than the price the infected area receives for only supplying demand arising in the infected area, P_2. Producers (or others) in the infected area now have an incentive to smuggle their product to the non-infected area to enjoy the higher prices. The exporting country must ensure that this does not happen because if an infected animal comes to the non-infected area then disease will possibly spread and the borders will close for the entire country.

The question is: how can the government prevent producers in the infected region from smuggling? One way would be to prevent animal movement out of infected areas. This would not be cost effective if the

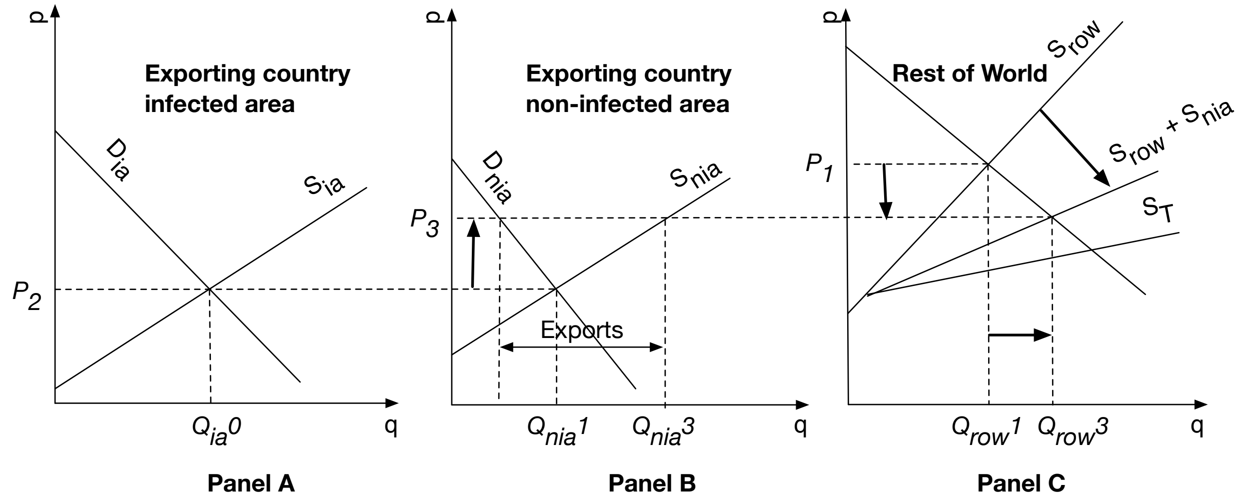


Figure 3.3: Prices and quantities when livestock disease outbreak is present and exporting is allowed from the non-infected area.

infected area had numerous ways for producers to move their animals. For example it would be difficult to effectively monitor every single roadway from Alberta to Saskatchewan. If there are geographic barriers that would prevent animal movements then monitoring could be an option. For example, the West Hawk Lake region in southern Manitoba could provide a cost-effective way to monitor animal movement east and west due to the geographic characteristics of the region (i.e. Canadian Shield). For Canada, this would likely be the only place that would be feasible and cost effective to monitor.

A comprehensive animal traceability system is another solution that has been discussed previously in chapter 1. It would require that all animals and premises be registered and any animals that are moved to a different premise be registered as well. This would mean than every animal would have a detailed history of where and when it has moved since birth. If an FMD outbreak occurred, the quarantine zones would be established and the traceability system would identify animals that have been through quarantined areas. Animals that are at risk of being exposed to FMD would be identified and isolated to prevent the spread of disease. The system would only work if there was full compliance by all producers and strong penalties would need to be in place to ensure full cooperation.

Another option would be to implement a policy that removes the incentive for producers to smuggle. This could be achieved by guaranteeing that producers in the infected area receive the same price as producers receive in the non-infected area. Trade from the infected area would still be closed, but producers would be receiving the same price for their product and thus there would be no incentive to smuggle. This results of this action are shown in Figure 3.4. Under a compensation policy there would be no change in the non-infected area or the ROW. In the infected area the price P_3 intersects the supply curve at quantity Q_{ia}^3. At this quantity the demand curve shows that the market clearing price is price P_4. The compensation required would be the price difference $P_3 - P_4$ for all units sold in the infected area. This is shown by the grey shaded box labelled 'Compensation'.

The economic impact resulting from the various scenarios can be assessed by measuring the changes in consumer and producer surplus.

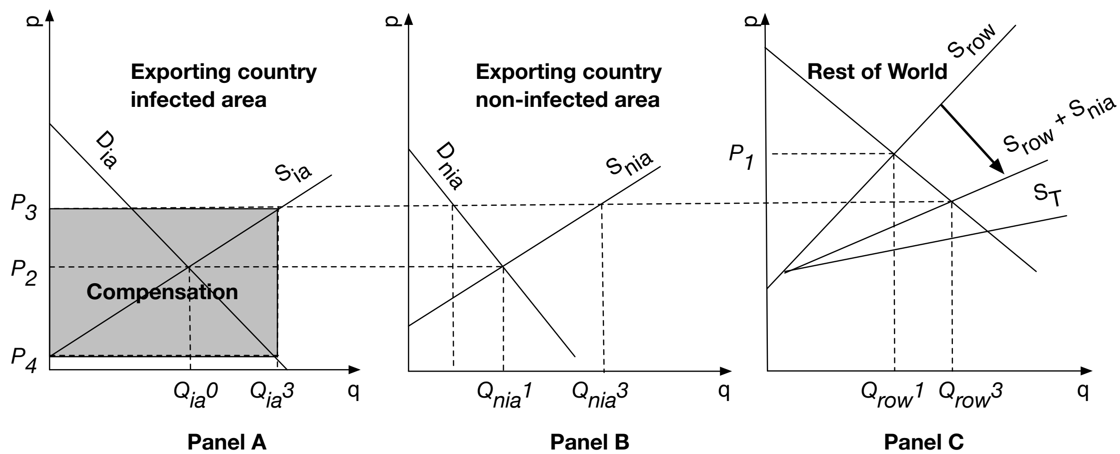


Figure 3.4: Prices and quantities when livestock disease outbreak is present and producers in infected area are compensated.

3.2 Modifications to the Theoretical Model

The previously discussed model was modified to fit the analysis performed in this study. The underlying theory is the same as the previously described model but the infected regions and export regions are defined more explicitly in accordance with the scenarios examined in the next chapter. The following assumptions are made:

3.2.1 Assumptions

1. Canada is the exporting country and the ROW is represented by the United States.

2. All livestock trade is between Canada and the US.

3. Live cattle used include slaughter cattle from provincial and federal plants and steer-heifer exports to the US. In order to simplify the model, dairy cattle are not included.

4. FMD outbreaks are assumed to occur in the beef (or cattle) sector and not spread to other species (e.g. hogs or sheep or dairy cattle).[3]

5. FMD outbreaks occur in western Canada.[4]

6. Western Canada exports product to the US and eastern Canada.

7. US exports to Canada go to eastern Canada only.[5]

8. Demand does not change after an FMD outbreak.[6]

Figure 3.5 shows the new diagram that is to be used. *Panel A* is the area where the FMD outbreak occurs. It will have its own supply and demand curves in the scenarios being examined. *Panel B* represents western Canada which includes British Columbia, Alberta, Saskatchewan and Manitoba. *Panel C* represents eastern Canada which includes all provinces east of Manitoba. *Panel D* represents the US. Initially price P_E represents the world price determined by the equilibrium price in the US. Price will change under the different scenarios being examined.

The areas marked by letters A through H that intersect price line P_E (Figure 3.5) will now be described. In *Panel B*, A represents the demand for livestock products in western Canada at the current world price P_E. At this price supply exceeds demand and the excess supply will be exported. B represents the amount of product exported to eastern Canada and C is the amount exported to the US, so that $A + B + C$ equals total quantity supplied in western Canada. Western Canada is therefore modelled as a net export region.

[3] Of course, FMD may spread to other species. This assumption restricts the economic assessment of the disease to the cattle and beef sector. Separate analysis could be undertaken for other species, but this is beyond the scope of this thesis.

[4] This is merely a simplifying assumption for the model. Disease outbreaks in eastern Canada could be a subject for future studies.

[5] It is assumed that western Canada produces enough product to supply demand completely.

[6] This reason demand does not shift is that FMD is not harmful to humans and so any meat products that come from an infected animal are safe to eat. In reality, demand could shift down if consumer preferences change as a result of an outbreak. This could be because consumers do want to consume meat that comes from a diseased animal even if the threat of illness is impossible. On the other hand, if prices decrease as a result of the disease, quantity demanded could increase as people switch to the lower priced product.

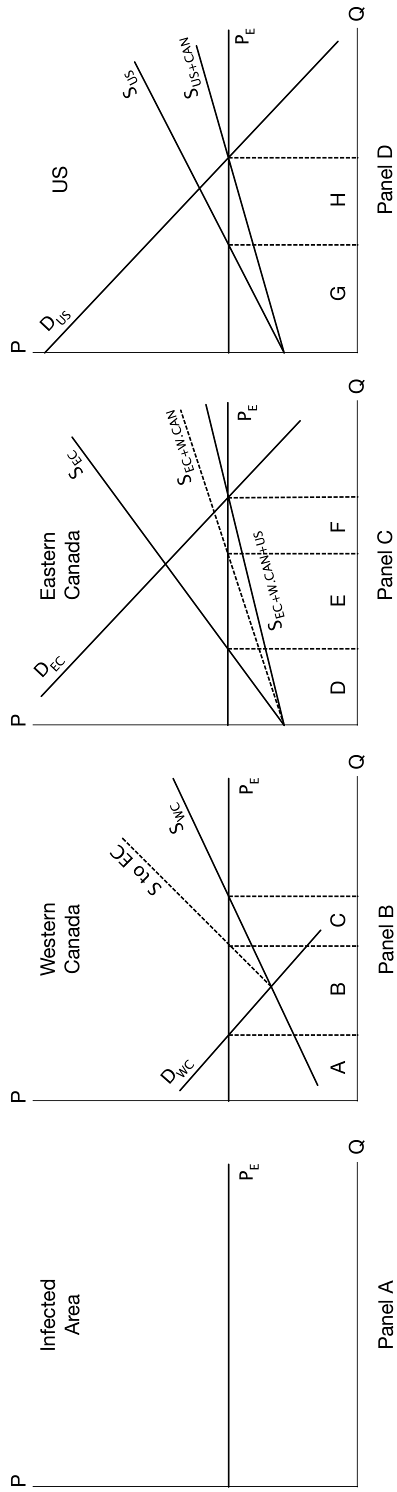


Figure 3.5: Modified Panel Diagram.

In *Panel C*, D is the amount of product produced in eastern Canada. E is the amount that is imported from western Canada and F is the amount imported from the US, giving total quantity demanded in eastern Canada of $D + E + F$. Eastern Canada is therefore modelled as a net beef importing region.

In *Panel D*, G is the amount of product produced in the US and H is the amount imported from Canada, giving total quantity demanded of $G + H$.

3.3 Description of Scenarios

This section details each scenario that will be investigated based on the previously discussed theoretical model and the modifications from the last section.

3.3.1 Base Case: Exporting when FMD is not present

The Base Case is the situation where Canada is disease-free and trade with the US operates as normal. Each of the scenarios will be compared to the Base Case conditions in order to assess changes in welfare. Figure 3.6 shows the relevant panels for the Base Case in which there is no infected area. In *Panel C* the US supply includes domestic supply plus imports from Canada. The equilibrium position with US demand determines the price P_E which applies to both countries. *Panel A* shows the situation in western Canada where price P_E determines the excess supply that is exported to eastern Canada and the US. *Panel B* shows the situation in eastern Canada where supply is comprised of domestic production, imports from western Canada and imports from the US.

The labels on the diagram are as follows. In *Panel A*, A is the supply of product produced in western Canada utilized to satisfy demand originating in western Canada. B is the amount of product that will be exported to eastern Canada and C is the amount that will be exported to the US. In *Panel B*, D is the amount of product produced in eastern Canada, E is the amount imported from western Canada and F is the amount imported from the US. In *Panel C*, G is the amount of product produced in the US and H is the amount imported from western Canada.

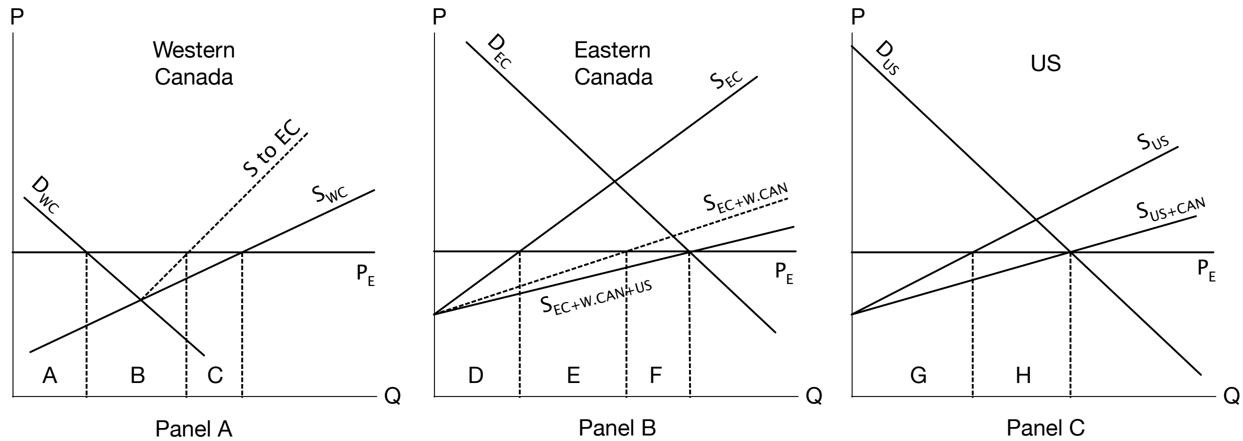


Figure 3.6: Base Case

3.3.2 Scenario 1: FMD outbreak occurs and export markets are closed

In Scenario 1 there is an FMD outbreak in Canada and the US closes its border to trade in livestock and meat completely until the outbreak is eradicated. Figure 3.7 shows the changes from the Base Case. Arrows show the direction of change. In *Panel A*, the US supply shifts by the amount of product that was imported from Canada (B). This causes supply to shift from S_{US+CAN} to S_{US}. The US market then moves to a new equilibrium price P_E2.

Canada no longer receives the the equilibrium price from the US and so it shifts to the domestic equilibrium price of P_E3. This is shown in *Panel B*. Supply and Demand remain the same in western Canada (*Panel C*) and eastern Canada (*Panel D*) but the price shifts down from the old price P_E to the new Canadian price P_E3. It is assumed that non-infected animal movement will still occur between western and eastern Canada during the outbreak and so an equilibrium price for the country can be determined. Once FMD has been eradicated and the US reopens its borders prices will revert back to the Base Case levels.

On *Panel A*, A is the amount of supply produced in the US before the outbreak. B is the amount that was imported from Canada before export markets were closed. On *Panel C*, C is the amount produced in western Canada for domestic demand after the border closure, D is the amount exported to eastern Canada and E was the amount exported to the US before exports ceased. On *Panel D*, F is the amount produced in eastern Canada, G is the amount imported from western Canada and H is the amount of net imports from the US.

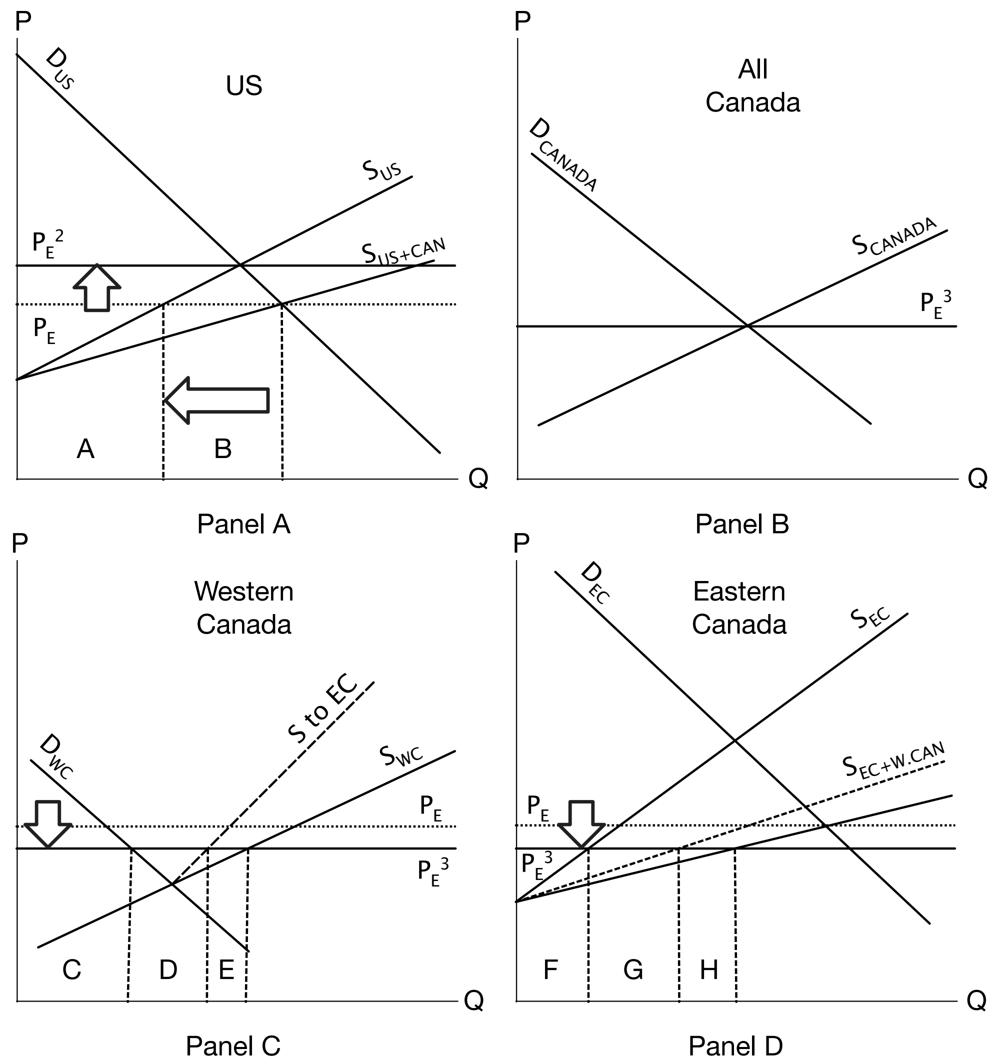


Figure 3.7: Scenario 1. FMD outbreak occurs and export markets are closed

3.3.3 Scenario 2: FMD outbreak occurs and exports are allowed from eastern Canada only

In Scenario 2 an FMD outbreak occurs in western Canada but the US will still allow trade from disease-free eastern Canada through a Regionalization Policy. Through the West Hawk Lake Zoning Initiative, it is assumed that animal movements are controlled such that no infected animals or meat move from west to east, thus ensuring that disease will not spread into eastern Canada. Until the FMD outbreak is eliminated no beef or cattle trade will be allowed from western Canada.

Figure 3.8 shows the changes for this scenario. Arrows shows the direction of change. In the US (*Panel C*) supply shifts left because imports are no longer allowed from western Canada. This shift results in a shift of the supply curve to S_{US} which results in a new equilibrium price P_E2 which is higher than the Base Case price of P_E. In eastern Canada supply also shifts left due to imports not being allowed from western Canada (*Panel B*). This causes a shift in the supply curve to S_{EC+US}. Eastern Canada now gets the higher US price P_E2. In western Canada (*Panel A*) supply remains unchanged and excess supply must be cleared at the western Canadian regional equilibrium price P_E3.

On *Panel A*, A is the amount of product produced in western Canada that will be consumed at the equilibrium price P_E3. On *Panel B*, B is the supply of beef produced in eastern Canada at the new price P_E2. C is the net import of beef from the US. On *Panel C*, D is the amount of supply produced in the US and E is the amount that was imported from western Canada before the outbreak.

3.3.4 Scenario 3: FMD outbreak occurs and exports can continue from 'disease-free' regions

In Scenario 3 an FMD outbreak occurs in western Canada but the US will still allow trade from disease-free eastern Canada as well as regions in western Canada that are disease-free.

In Figure 3.9 the US situation is shown in *Panel D*. Supply in the US shifts left to include only imports from the non-infected regions of western Canada. This leads to a new equilibrium price P_E2. In eastern Canada (*Panel C*) supply shifts left to include only imports from disease-free parts of western Canada.

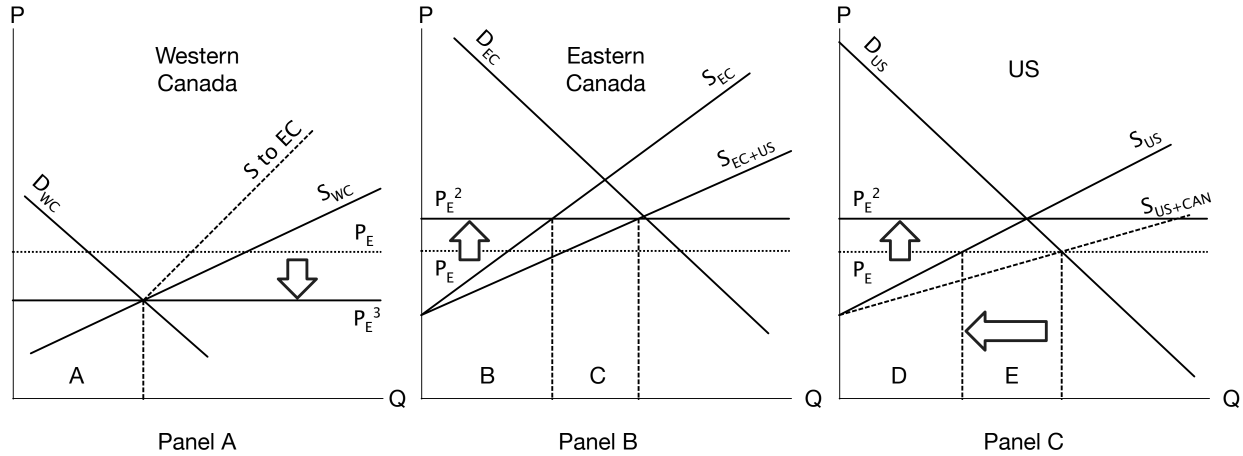


Figure 3.8: Scenario 2. FMD outbreak occurs but trade from E. Canada allowed.

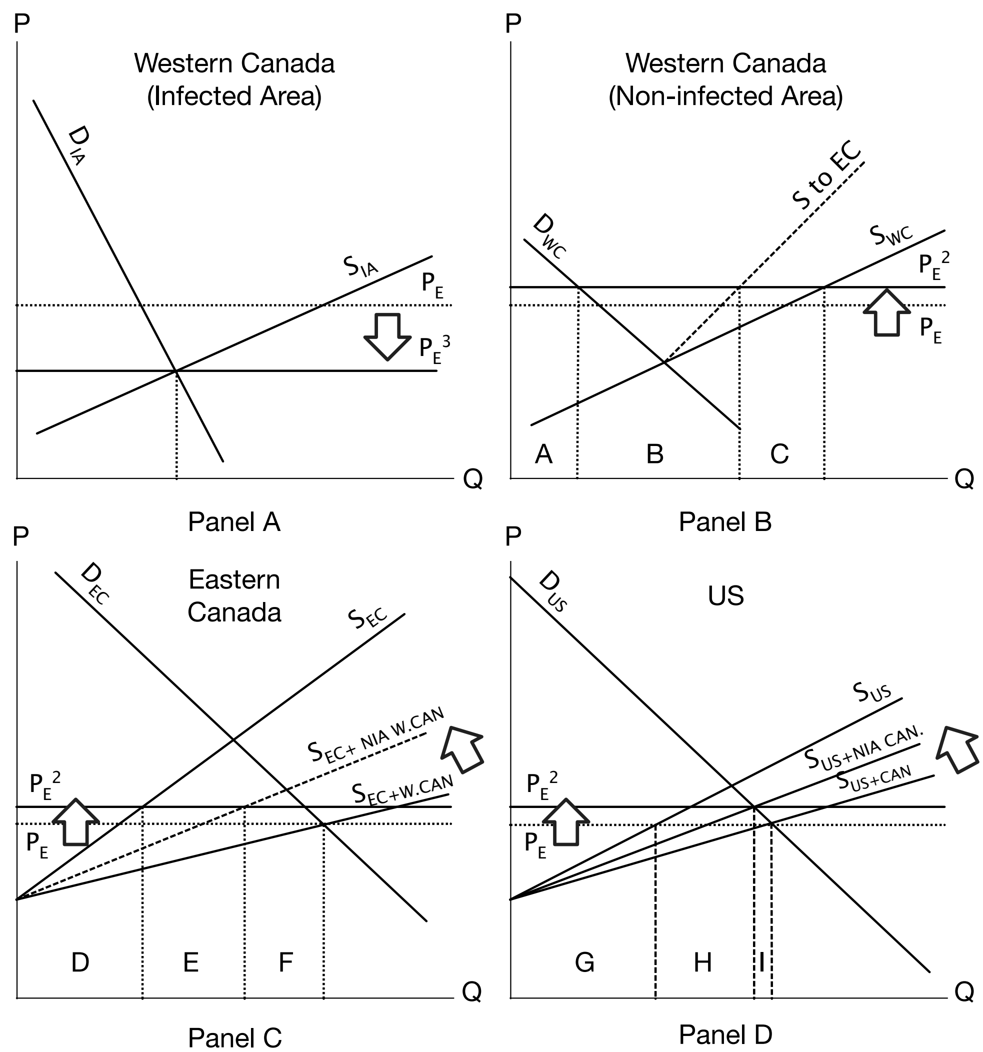


Figure 3.9: Scenario 3. FMD outbreak occurs but trade from disease-free Canada allowed.

Eastern Canada now trades at the new US price of P_E2. *Panel B* shows the situation in disease-free western Canada. Supply shifts left to account for exports to eastern Canada that are no longer allowed from the infected area. Non-infected western Canada also gets the US price P_E2. *Panel A* now represents the infected-area of western Canada. Supply does not change and price will go to the equilibrium value of P_E3 where supply equals demand in the region.

3.3.5 Scenario 4: FMD outbreak occurs and non-trading producers in infected area are compensated

Scenario 4 is similar to Scenario 3 except that the infected area of western Canada gets the US price P_E2. This price is the regional equilibrium price received plus additional compensation to get to the effective price P_E2. In Scenario 3 the infected-area producers received a lower price for product than the rest of Canada. This would give producers an incentive to smuggle their animals to higher price regions and make the spread of disease far more likely. By giving producers in the infected-area the same price as the rest of Canada the incentive to smuggle is removed.

Figure 3.10 shows the changes in the infected-area (*Panel A*). The price increases from the old US price P_E to the new price P_E2. The new price P_E2 intersects the supply curve S_{IA} at quantity Q_4. In order to clear the quantity Q_4, price would need to be P_4 which is where Q_4 intersects the demand curve D_{IA}. The compensation required to clear the local market is equal to the grey-shaded rectangle. All other panels are unchanged from Scenario 3 because trade is still restricted from the infected-area.

3.4 Next Steps

This concludes the discussion of the scenarios that will be examined. The next chapter presents the empirical analysis based on these scenarios, and the changes in welfare from the Base Case.

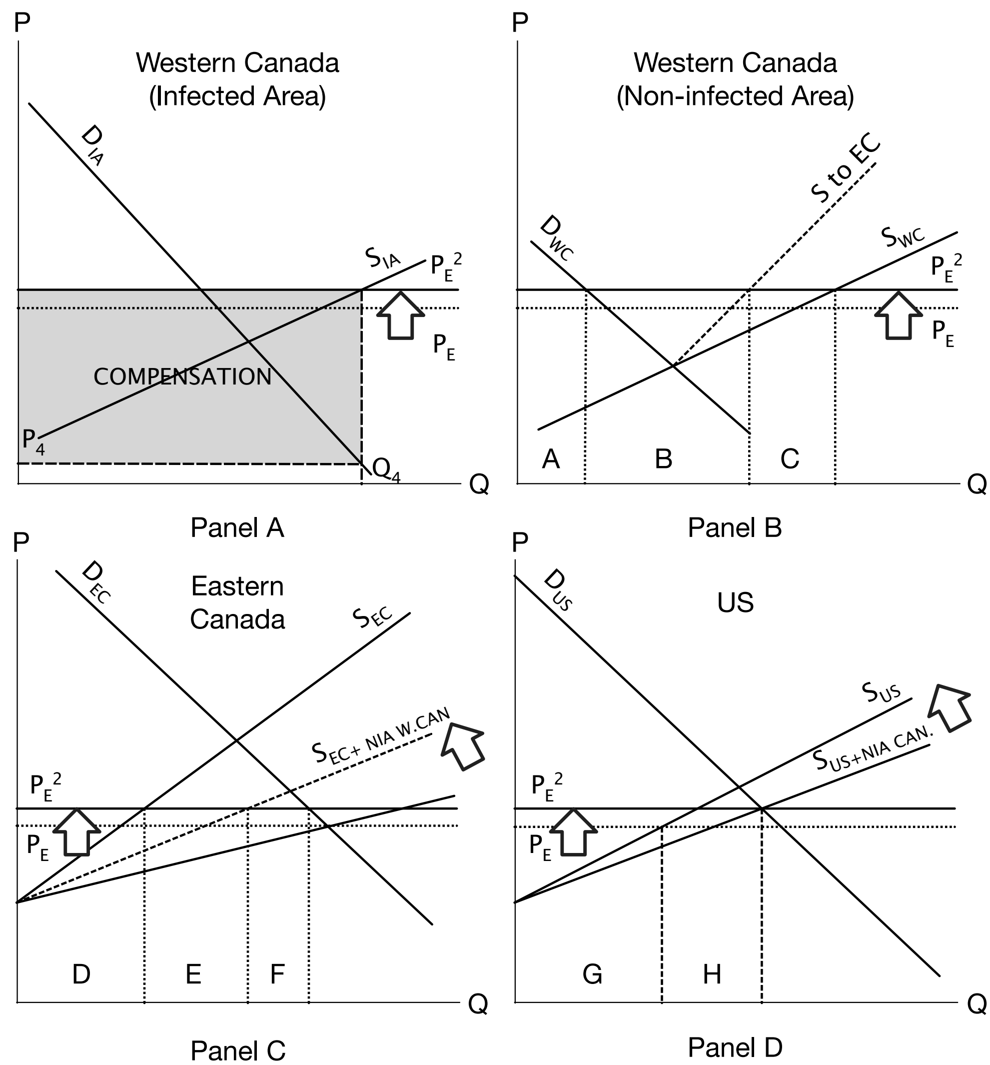


Figure 3.10: Scenario 4. FMD outbreak occurs but trade from disease-free Canada is allowed and all regions get the same price

Chapter 4

Analysis

Based on the theoretical model discussed in Chapter 3, with the modifications that were discussed, the focus now moves to an empirical analysis. Under the different scenarios welfare changes (i.e. consumer surplus, producer surplus and total surplus) are calculated with respect to the Base Case in order to measure the impact of different assumptions about the effectiveness of zoning and traceability in the event of an FMD outbreak. The analysis focuses on the effects on the industry in Canada and therefore welfare changes are not calculated for the US market.

4.1 Assumptions

This section discusses the assumptions underlying the analysis.

1. The focus is on trade between Canada and the US. In this case the US represents the "rest of the world" referred to in the theoretical model.

2. All quantities are in tonnes of beef/meat.

3. All prices are in $/tonne

4. Live cattle numbers are converted to beef/meat equivalents in tonnes.

5. Beef is imported from the US to eastern Canada only. It is assumed that western Canada does not import beef from the US because it can produce sufficient quantities to satisfy local demand.

6. Excess western supply goes to eastern Canada and the US.

7. Supply and Demand curves are linear and are derived from an observed price/quantity pair and a supply/demand elasticity.

4.2 Empirical Model

Figure 4.1 represents the theoretical model adapted for the Canada-US market. *Panel A* represents the "Infected Area" where the disease outbreak will take place. In this model the "Infected Area" will be located somewhere in Alberta and will contain extrapolated regional supply and demand curves. *Panel B* labeled "Western Canada (Non-infected area)" represents all of British Columbia, Saskatchewan, Manitoba and the part of Alberta that is not in the "Infected Area". In some of the scenarios there will be no "Infected Area" and so the "Western Canada" panel will represent all of Alberta plus the other western provinces. *Panel C* ("Eastern Canada") represents Ontario and all provinces east of it. Data from the Northwest Territories is also included in this panel. Finally *Panel D* ("US") represents all states in the US market.

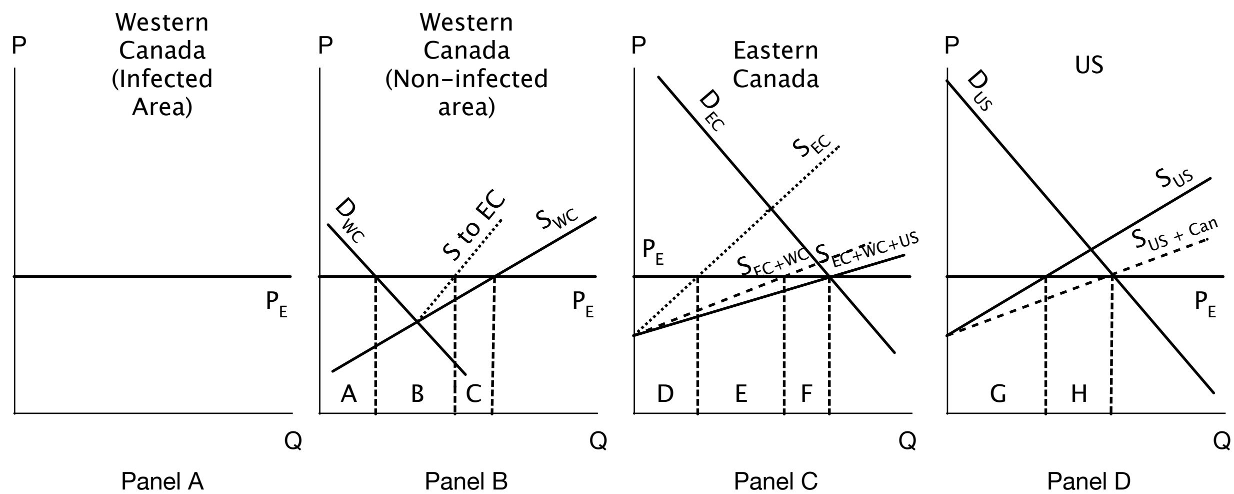


Figure 4.1: Empirical Model

All of the panels show Supply and Demand curves plus prices. The line P_E refers to the equilibrium price that is being used in each panel. This price will vary under the different scenarios but it will be used as the initial price point when there is no outbreak and trade is conducted between Canada and the US. There are some other features about the diagram that need to be discussed.

In *Panel B*, the demand curve D_{WC} crosses P_E at quantity A. Equilibrium price P_E is derived from the World Market represented for simplicity by the US market. A is the consumption of beef in western Canada. The supply curve for western Canada S_{WC} also crosses price line P_E which can be seen is at a higher point than the equilibrium price at the intersection of supply and demand. This distance between demand and supply is the quantity of beef exported out of western Canada. Western Canada is modelled as a net exporter of beef. Part of the excess is exported to the US and the rest is exported to eastern Canada. The quantity labelled B is the amount that is exported to eastern Canada and C is the amount exported to the US.[1]

The dashed line in *Panel B* labeled *S to EC* represents the amount of product that is exported to eastern Canada. The remaining excess product is exported to the US. In *Panel C* the demand curve D_{EC} crosses price line P_E to give quantity $D + E + F$ in eastern Canada at that price. Eastern Canada is modelled as a net importer of beef. Quantity D represents the quantity of beef produced in eastern Canada. Quantity E represents the quantity that is imported from western Canada. Quantities $D + E$ is represented by supply curve $S_{EC+W.CAN}$ which includes the quantity produced in eastern Canada plus the quantity imported from western Canada. Quantity F represents the quantity of beef imported from the US. Eastern Canada is an importer of beef from western Canada and the US which is in contrast to western Canada which we assume imports no product. In reality eastern Canada exports some product to the US but it imports a greater quantity than it exports.

Panel D represents the "US" market. The US market determines the price that Canada will use in the various scenarios and represents the *ROW* market used in the theoretical model. P_E is determined at the US market's equilibrium value between supply and demand. Quantity G represents the supply of beef produced domestically in the US and H is the quantity imported from Canada. The sum of these quantities determines the supply curve $S_{US+Canada}$ and P_E is determined at the intersection of S_{US+CAN} with the demand curve D_{US}.

4.3 Example of solving for the Demand curve

This section will explain the theory used to calculate the demand curve. The theory for the supply curve is exactly the same except for the elasticity value used.

Supply and demand curves for this analysis will be assumed to be linear at all points. The curves are derived by finding two points and then calculating the slope and intercept values using basic geometry.

[1] Although the diagram shows the amount B is greater than C, in actuality this may not be the case.

Figure 4.2 shows an example.

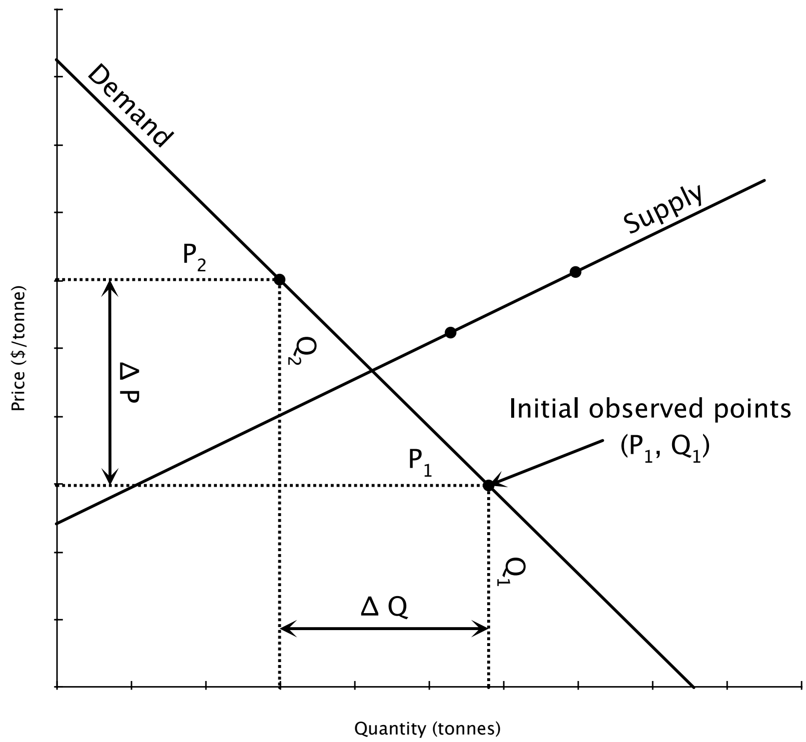


Figure 4.2: Supply-Demand curves

On the figure there are two points shown that fall along the demand curve (similarly for the supply curve). Initially all that is known is one pair of points P_1 and Q_1 which are the observable price and quantity. The key to solving for the other pair of points is the price elasticity of demand. Price elasticity of demand is defined by equation 4.1.

$$E_D = (\Delta Q/\Delta P) * (P_1/Q_1) \tag{4.1}$$

The values of P_1, Q_1 and the price elasticity of demand E_D are known. ΔP is calculated by increasing P_1 by 10% to get P_2 and subtracting to get the difference.[2] This is shown in the following equations:

$P_2 = P_1 * 1.1$

$\Delta P = P_2 - P_1$

The only unknown left is ΔQ which can be solved by rearranging equation 4.1. The new equation for

[2]Note: The increase of price by 10% in the calculation is an arbitrary value. The elasticity value determines the slope and intercept of the line so any value could be used.

ΔQ is shown in equation 4.2.

$$\Delta Q = (Q_1/P_1) * \Delta P * E_D \tag{4.2}$$

Plugging P_1, Q_1, ΔP and E_D into equation 4.2 solves for ΔQ. All that is left now is to solve for Q_2 which is solved as follows:

$Q_2 = Q_1 + \Delta Q$

Now that the two pairs of points are calculated the slope (m) and intercept (b) of the line can be calculated. Slope (m) is calculated as follows:

$m = (P_2 - P_1)/(Q_2 - Q_1)$

Once slope is calculated, intercept (b) can then be calculated as follows:

$b = P_1 - m * Q_1$

The equation of the linear demand curve is simply the equation of a line ($P = m * Q + b$). Now any point along the demand curve can be determined given a price or quantity value. Supply curves are derived exactly the same way but substituting the elasticity of supply (E_S) for the elasticity of demand (E_D) in equations 4.1 and 4.2 and solving for the remaining point.

4.4 Actual Supply/Demand Calculations

Supply and demand curves need to be calculated for Canada and the US. As was shown in the previous section, each curve needs an observed point (P_1, Q_1) and an elasticity value. The elasticity values used were found in existing literature. The values and their source are shown in Table 4.1.

TYPE	COUNTRY	VALUE	DESCRIPTION	SOURCE
E_D	Canada	-0.4340	Unconditional, uncompensated price elasticity	(Cranfield, 2012), Table 7
E_S	Canada	0.6830	LR Retail Price Elasticity	(Cranfield and von Massow, 2010), Table A.3
E_D	US	-0.4199	Estimated compensated elasticity for demand , beef price	(Tonsor, Mintert, and Schroeder, 2010), Table 3
E_S	US	0.9100	Own price supply elasticity (hq)	(Eenoo, Peterson, and Purcell, 2000), Appendix C

Table 4.1: Elasticity Values and sources

Table 4.2 shows the values of Q_1 that will be used to solve for Q_2 in the following examples given an initial price (P_1) and an elasticity (Table 4.1). Table 4.3 shows the values calculated for Canada and the US for demand curves using the methodology described in the previous section. The source of the data and calculations for each row will now be explained.

	W. CANADA	E. CANADA	CANADA TOTAL	US
DEMAND (Q_1, Tonnes)	355,469.7	796,542.8	1,152,012.5	11,102,646.2
SUPPLY (Q_1, Tonnes)	1,150,365.1	383,225.1	1,533,590.2	11,102,646.2

Table 4.2: Base Case Supply and Demand Q_1 values

	DEMAND	W. CANADA	E. CANADA	CANADA TOTAL	US
(a)	P_1	2,156.41	2,156.41	2,156.41	2,156.41
(b)	Q_1	355,469.7	796,542.8	1,152,012.5	11,102,646.2
(c)	P_2	2,372.05	2,372.05	2,372.05	2,372.05
(d)	ΔP	215.64	215.64	215.64	215.64
(e)	E_D	-0.4340	-0.4340	-0.4340	-0.4199
(f)	ΔQ	-15,427.38	-34,569.96	-49,997.34	-466,200.11
(g)	Q_2	340,042.31	761,972.85	1,102,015.16	10,636,446.09

Table 4.3: Demand Curve values

4.4.1 (a) P_1

This is the initial price determined by the US market and used in Canada. The derivation of P_1 is explained in detail in Appendix A.

4.4.2 (b) Q_1

These are the initial Q_1 volumes per region in Canada and the US (Table 4.2). The derivation of Q_1 is explained in detail in Appendix A. Q_1 estimates for the base case and all scenarios are found in Appendix B.

4.4.3 (c) P_2

This value is calculated by changing P_1 by 10% as shown in the following equation: $P_2 = P_1 * 1.1$

4.4.4 (d) ΔP

This value is the difference from P_2 to P_1 as shown in the following equation: $\Delta P = P_2 - P_1$

4.4.5 (e) E_D

This value is the elasticity of demand that was shown in Table 4.1.

4.4.6 (f) ΔQ

This number is calculated using equation 4.2 as discussed in the previous section with the quantities already obtained.

4.4.7 (g) Q_2

This quantity is calculated as follows: $Q_2 = Q_1 + \Delta Q$

Now that the points P_2 and Q_2 are solved, the slope m and intercept b can be solved as detailed in the previous section. This will allow the calculation of any point P or Q along the demand curve. The estimates calculated for the supply curve are shown in Table 4.4. The process of calculating the data is the same as for demand (substituting E_S for E_D) so the explanation for each entry will not be repeated.

SUPPLY	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	1,150,365.1	768,116.4	1,533,590.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
E_S	0.6830	0.6830	0.6830	0.9100
ΔQ	78,569.9	52,462.4	104,744.2	1,010,340.8
Q_2	1,228,935.0	820,578.8	1,638,334.4	12,112,987.0

Table 4.4: Supply Curve data points

Data tables and supply/demand calculations for all scenarios based on the previous calculations are found in Appendix B. The following sections discuss the various scenarios in detail and any assumptions that are made.

4.5 Base Case

The Base Case is the pre-outbreak condition in which there is full trade between Canada and the US with no restrictions. Figure 4.3 shows the supply and demand curves for Canada and the US based on the data and procedures described in the previous sections. All values are reported in appendix B. *Panel A* shows the equilibrium condition in the US where P_1 is \$2,156.41 and is also known as the “ROW Price”. *Panel B* shows the equilibrium condition in Canada where P_2 is \$1,624.66.[3] Since the P_1 price is greater than the P_2 price there will be trade which is shown by Q_S being greater than Q_D at P_1.

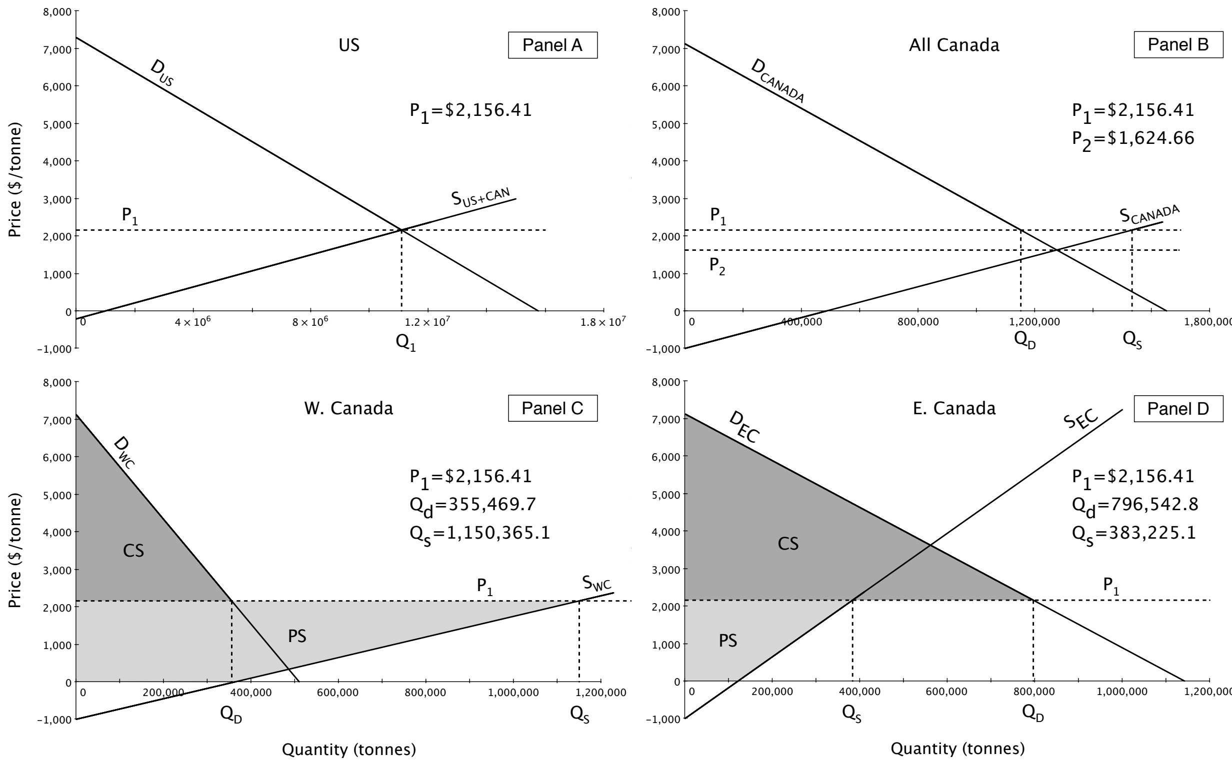


Figure 4.3: Base Case Diagram

Panels C and *D* shows the regional supply and demand curves for Canada in the Base Case with *ROW* price P_1. Western Canada (*Panel C*) shows that at the price P_1 there is a surplus of product supplied because supply exceeds demand. The excess product is exported to eastern Canada and the US. Welfare will be calculated for consumers and producers as discussed in chapter 1. In the remaining scenarios the supply curves and prices will change resulting in new welfare values. These will be compared to the base case here in order to see if welfare increased or decreased and by how much.

Recall from chapter 1 that welfare is measured by calculating the area between the curves and the price line. Consumer Surplus (CS) is the area below the demand curve and above the price line and Producer

[3]Canada’s equilibrium price was calculated by finding the price and quantity where supply equals demand.

Surplus (PS) is the area above the supply curve and below the price line. In *Panels C* and *D*, CS is the medium-grey shaded region and PS is the light-grey shaded region. Under the various scenarios the price and supply curves will change and, therefore, surplus will also change. These changes in surplus will be compared to the base case in order to measure the effects the changes have on welfare. For each scenario the changes to welfare compared to the base case will be shown. A summary and discussion of all the results is found at the end of this chapter.

4.6 Scenario 1

In Scenario 1 an outbreak of FMD occurs somewhere in Canada and trade is immediately halted with the US. The following assumptions are made.

4.6.1 Assumptions

1. Supply and Demand will not change in Canada.
2. US does not import from Canada or export to Canada during the outbreak.[4]
3. The location of the outbreak is irrelevant because exports are halted for the entire country.
4. Exports from W. Canada to E. Canada will continue as normal.

4.6.2 Changes from Base Case

Figure 4.4 shows the effects of trade being halted. Arrows on the figure show the direction of change. On *Panel A*, supply in the US market decreases from Q_{US+CAN} to Q_{US}. This causes the US supply curve to shift from S_{US+CAN} to S_{US}. Demand remains constant and a new equilibrium price in the US (P_3) is determined at the new equilibrium. The new equilibrium price in the US (P_3) is \$2,213.48.

[4]Technically the US could still export to Canada but it is likely that the US would not be competitive due to the decline in price in Canada resulting from the loss of exports.

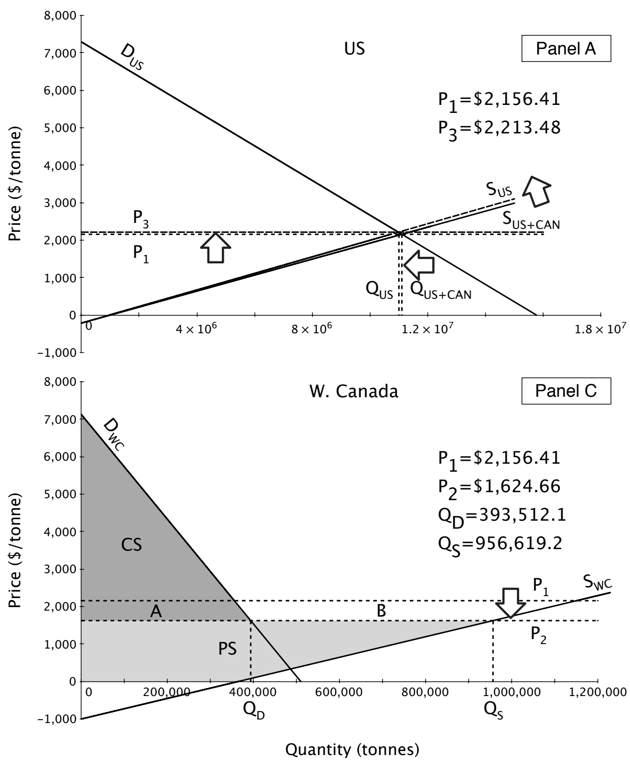


Figure 4.4: Scenario 1: Changes to price and surplus in US and Canada

Without trade to the US the price in Canada is determined by the domestic equilibrium price. This is shown in Figure 4.4 - *Panel B*. The supply and demand curves for Canada are shown and the equilibrium price is \$1,624.66 (P_2). P_2 was determined by solving for price when supply equals demand. All values are reported in full in appendix B.

Panels C and *D* show the changes that happen in Canada. In western Canada (*Panel C*) price shifts downwards from P_1 to P_2. As a result of the new price CS increases by the amount shown as A and PS decreases by the amount $A + B$. In eastern Canada (*Panel D*) the shift in price causes CS to increase by amount $C + D$ while PS decreases by amount C.

Table 4.5 shows the changes in price and quantities from the Base Case to Scenario 1. The new equilibrium price in Canada was a decrease from the Base Case price causing an increase in quantity demanded by consumers and a decrease in the quantity supplied by producers. Table 4.6 shows the changes in CS, PS and TS moving from the Base Case to Scenario 1. The percent change is shown as well as the dollar amount change. The percent change in surplus is calculated as shown by Equation 4.3.

	Western Canada			Eastern Canada		
Scenario	P	Q_D	Q_S	P	Q_D	Q_S
Base Case	2,156.41	355,469.7	1,150,365.1	2,156.41	796,542.8	383,225.1
Scenario 1	1,624.66	393,512.1	956,619.2	1,624.66	881,789.0	318,681.9
Change	-531.75	38,042.4	-193,745.9	-531.75	85,246.2	-64,543.2

Table 4.5: Scenario 1: Quantity change from Base Case

		Consumer Surplus (CS)		
Region	Base Case	Scenario 1	$\Delta CS(\%)$	$\Delta CS(\$)$
W. Canada	883,108,748	1,082,244,230	22.5	199,135,482
E. Canada	1,978,885,808	2,425,112,143	22.5	446,226,335
		Producer Surplus (PS)		
Region	Base Case	Scenario 1	$\Delta PS(\%)$	$\Delta PS(\$)$
W. Canada	1,633,513,823	1,073,319,526	-34.3	-560,194,297
E. Canada	544,178,103	357,558,642	-34.3	-186,619,461
		Total Surplus (TS)		
Region	Base Case	Scenario 1	$\Delta TS(\%)$	$\Delta TS(\$)$
W. Canada	2,516,622,571	2,155,563,757	-14.3	-361,058,815
E. Canada	2,523,063,912	2,782,670,785	10.3	259,606,873

Table 4.6: Scenario 1: Surplus Change from Base Case

$$\%Change = \frac{Number2 - Number1}{Number1} * 100 \tag{4.3}$$

CS has a significant increase whereas PS has an even larger decrease. In terms of the graphs it can be seen that a lower price results in a larger area that makes up the CS as well as a smaller area for PS. In real world terms, a rational consumer would prefer to pay less for the same product and therefore the lower price increases the welfare (happiness) of the consumer. Conversely a lower price for the same product will mean the producers are making less money than they were at the higher price. Therefore the welfare of producers decreases.

4.7 Scenario 2

In Scenario 2 there is an FMD outbreak somewhere in western Canada which is comprised of the provinces British Columbia, Alberta, Saskatchewan and Manitoba. While the outbreak is being dealt with trade with the US will still be allowed from eastern Canada, comprised of all the provinces east of Manitoba. In order for trade to be allowed from the east, animal movements must be closely monitored to prevent movement of animals from west to east.[5] As there are no exports out of western Canada, the market in the US will adjust accordingly and come to a new equilibrium price. The new US price will be extended to eastern Canada while the western Canada market will move to a new regional equilibrium price.

4.7.1 Assumptions

1. FMD will be contained to western Canada through animal movement monitoring at West Hawk Lake, Manitoba, plus border checks preventing exports from western provinces to western states.

2. Total supply to the US will decrease by the amount of product normally exported from western Canada.

3. The US market will move to a new equilibrium price.

4. Eastern Canada will trade at the new US (world) price.

5. Supply in W. Canada will not change so excess supply earmarked for export will need to be cleared within W. Canada.

6. Western Canada price will be determined by the regional equilibrium price.

Figure 4.5 shows the results of the changes in trade. All numbers are reported in appendix B. The arrows in the diagram show the direction of change. In the US (*Panel A*) supply decreases by the amount of product normally imported from western Canada when there is trade. This decrease in supply quantity results in a shift of the supply curve from S_{US+CAN} to $S_{US-W.CAN}$. The US price moves to a new equilibrium price P_2. In eastern Canada (*Panel C*) price changes to the new US (world) equilibrium price P_2. In western Canada (*Panel B*) price moves to the market clearing equilibrium price P_3 where supply equals demand.

[5] Refer to the discussion of The West Hawk Lake Zoning Initiative in chapter 1.

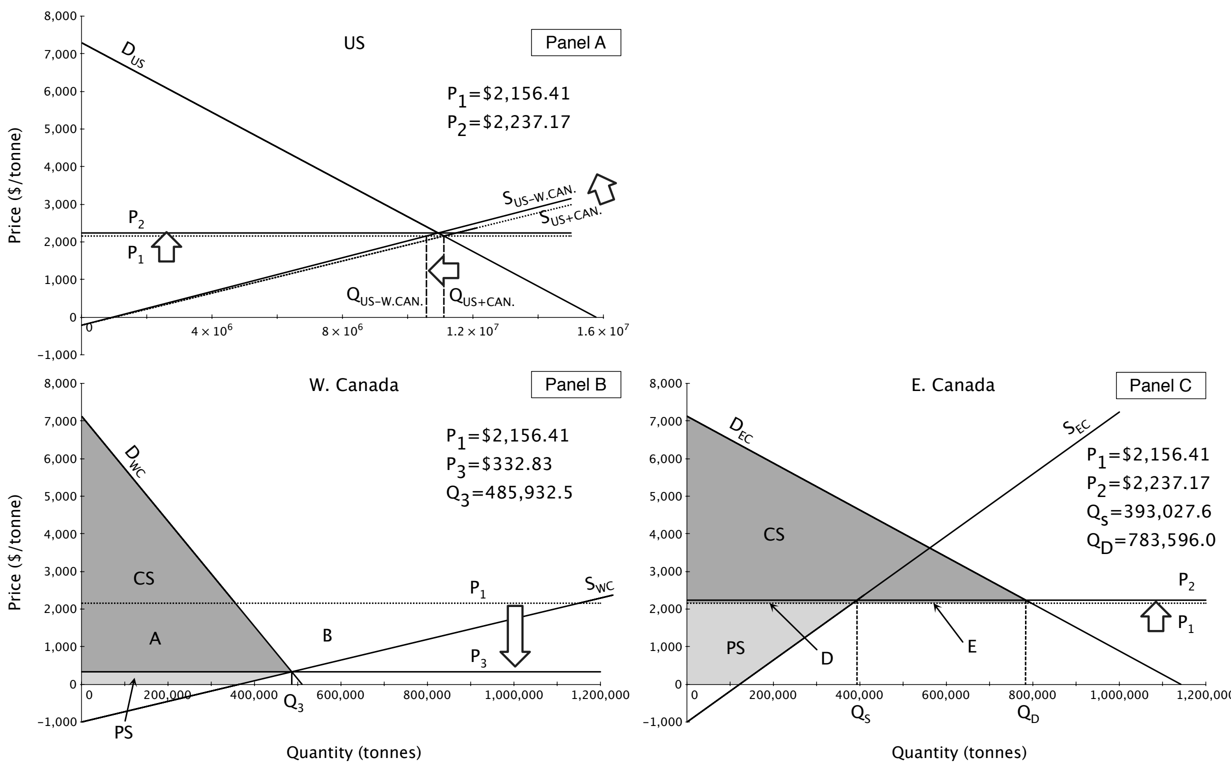


Figure 4.5: Scenario 2: Trade with US and Eastern Canada

4.7.2 Changes from Base Case

Table 4.7 summarizes the changes in surplus from the Base Case in this scenario. CS increases greatly in western Canada due to the lower price consumers now pay for the beef. PS on the other hand is greatly decreased in this scenario. Once more the change can be seen visually by inspecting the changes in area for *Panel B*. The changes in surplus for eastern Canada are much smaller than western Canada due to the smaller change in price, as can be seen in Table 4.8. Consumers now pay a higher price, resulting in a decrease in surplus, whereas producers have a higher surplus through selling product at a higher price.

	Western Canada			Eastern Canada		
Scenario	P	Q_D	Q_S	P	Q_D	Q_S
Base Case	2,156.41	355,469.7	1,150,365.1	2,156.41	796,542.8	383,225.1
Scenario 2	332.83	485,932.5	485,932.5	2,237.17	783,596.0	393,027.6
Change	1,823.58	-130,462.8	664,432.6	-80.76	12,946.8	-9,802.5

Table 4.7: Scenario 2: Quantity change from Base Case

		Consumer Surplus (CS)		
Region	Base Case	Scenario 2	$\Delta CS(\%)$	$\Delta CS(\$)$
W. Canada	883,108,748	1,650,292,696	86.9	767,183,948
E. Canada	1,978,885,808	1,915,080,029	-3.2	-63,805,780
		Producer Surplus (PS)		
Region	Base Case	Scenario 2	$\Delta PS(\%)$	$\Delta PS(\$)$
W. Canada	1,633,513,823	141,550,469	-91.3	-1,491,963,354
E. Canada	544,178,103	575,523,077	5.8	31,344,974
		Total Surplus (TS)		
Region	Base Case	Scenario 2	$\Delta TS(\%)$	$\Delta TS(\$)$
W. Canada	2,516,622,571	1,791,843,165	-28.8	-724,779,406
E. Canada	2,523,063,912	2,490,603,106	-1.3	-32,460,806

Table 4.8: Scenario 2: Surplus Change from Base Case

4.8 Scenario 3a

In this scenario a large FMD outbreak occurs in central Alberta where cattle are highly concentrated, as shown in Figure 4.6. The map shows a large concentration of feedlots in the shaded areas where the outbreak occurs. The regions consist of Census Divisions 4802, 4805, 4806 and 4808 which comprise 40.6% of Alberta's cattle population. Measures go into effect to quarantine infected areas and animal movements are halted. Due to the large concentration of cattle it is estimated that a 25% cull will be required to contain the outbreak even with FMD counter-measures in effect (animal traceability systems, quarantines, zoning, etc).[6] It is assumed that the region has the slaughter capacity in order to do the 25% cull. Table 4.9 shows the slaughter cattle populations before the outbreak and the number that are culled in controlling the outbreak.

[6] 25% cull assumptions based on discussion with Cheryl Waldner (DVM, PhD).

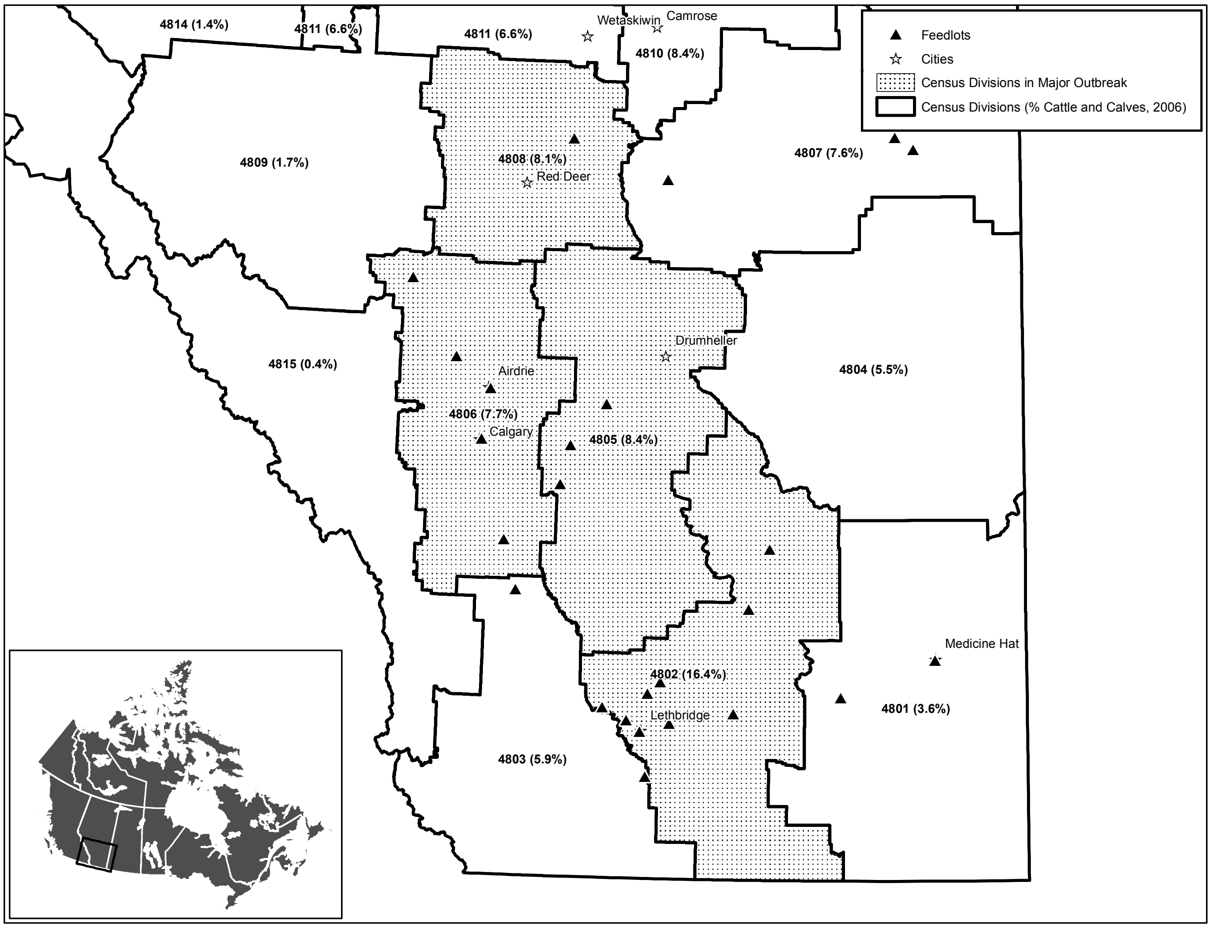


Figure 4.6: Map of Large Outbreak Location

CANADA, 2010	INFECTED AREA
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	384,513.3
% Culled	25.0
# Head Culled	96,128.3
REMAINING SLAUGHTER CATTLE	288,385.0

Table 4.9: Slaughter Cattle populations before and after large outbreak

A new base case is constructed to separate the numbers of the "Infected Region" from the rest of western Canada. This is shown in Table 4.10. The "Infected Area" numbers are set to 40.6% of the Alberta numbers and the "Rest of western Canada" numbers are set to the original values minus the numbers in the "Infected Area". Eastern Canada data remains the same as before.

CANADA, 2010	INFECTED AREA	REST OF W. CANADA	E. CANADA
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	384,513.3	576,237.8	346,871.4
Total Steer-Heifer Exports to US (Tonnes)	64,857.8	124,756.2	36,353.7
Beef and Veal Exports Canada to US (Tonnes)	88,923.3	131,466.8	88,396.9
TOTAL Exports (tonnes)	153,781.1	256,223.0	124,750.6
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0
Population, 2010	1,710,064	8,804,445	23,561,099
SUPPLY (Tonnes)	449,371.1	700,994.0	383,225.1
DEMAND (Tonnes)	295,590.0	444,771.0	411,651.5
WEIGHTED DEMAND (Tonnes)	57,813.1	297,656.6	796,542.8

Table 4.10: Large Outbreak Base Case Data

Once the outbreak occurs trade is cut off from the infected area. Trade both inter-provincial and with the US still occurs in eastern Canada and the Rest of western Canada. The following assumptions are made:

4.8.1 Assumptions

1. Animal traceability is utilized to minimize the spread of disease and the duration of the outbreak.

2. Infected Area slaughter cattle decreases by cull amount (25%).

3. Infected Area has the capacity to perform the 25% cull.[7]

4. Infected Area is quarantined and exports go to 0.

5. Rest of W. Canada numbers stay the same as they were before the outbreak.

6. E. Canada Supply decreases by amount not imported from Infected Area.

7. US supply decreases by amount not imported from Infected Area.

8. US P_E will change and new P_E will be used in Canada (except in the Infected Area).

9. Infected Area will trade at local equilibrium price to clear the market.

[7] This is a simplifying assumption but it is acknowledged that central Alberta has major facilities that service all of western Canada.

The post-outbreak data are shown in Table 4.11. Slaughter cattle numbers in the "Infected Area" are decreased by 25% and export numbers are set to 0.

CANADA, 2010	INFECTED AREA	REST OF W. CANADA	E. CANADA
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	288,385.0	576,237.8	346,871.4
Total Steer-Heifer Exports to US (Tonnes)	0.0	124,756.2	36,353.7
Beef and Veal Exports Canada to US (Tonnes)	0.0	131,466.8	88,396.9
TOTAL Exports (tonnes)	0.0	256,223.0	124,750.6
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0
Population, 2010	1,710,064	8,804,445	23,561,099
SUPPLY (Tonnes)	288,385.0	700,994.0	383,225.1
DEMAND (Tonnes)	288,385.0	444,771.0	411,651.5
WEIGHTED DEMAND (Tonnes)	57,813.1	297,656.6	796,542.8

Table 4.11: Large Outbreak Post-Outbreak Data

Figure 4.7 shows the changes to the supply-demand curves and prices in the regions post-outbreak. In the US (*Panel D*) supply shifts slightly by the amount that was exported from the "Infected Area". This change results in a new P_E of \$2,179.08. This is the price that the trading regions of Canada will also receive. The supply curve in eastern Canada (*Panel C*) shifts by the amount of product that was imported from the "Infected Area". Surplus areas are calculated based on the new "ROW Price". In the rest of western Canada the supply/demand curves are unchanged but surplus will change based on the "ROW Price". In the "Infected Area" supply shifts by the amount of cattle culled. As *Panel A* shows, the equilibrium condition would result in a negative price so effectively the price drops to \$0.[8]

[8]Setting price to \$0 is a simplification. In reality, price may actually rise if animals cannot be moved to slaughter facilities and converted to food. A decrease in the supply would cause price to increase.

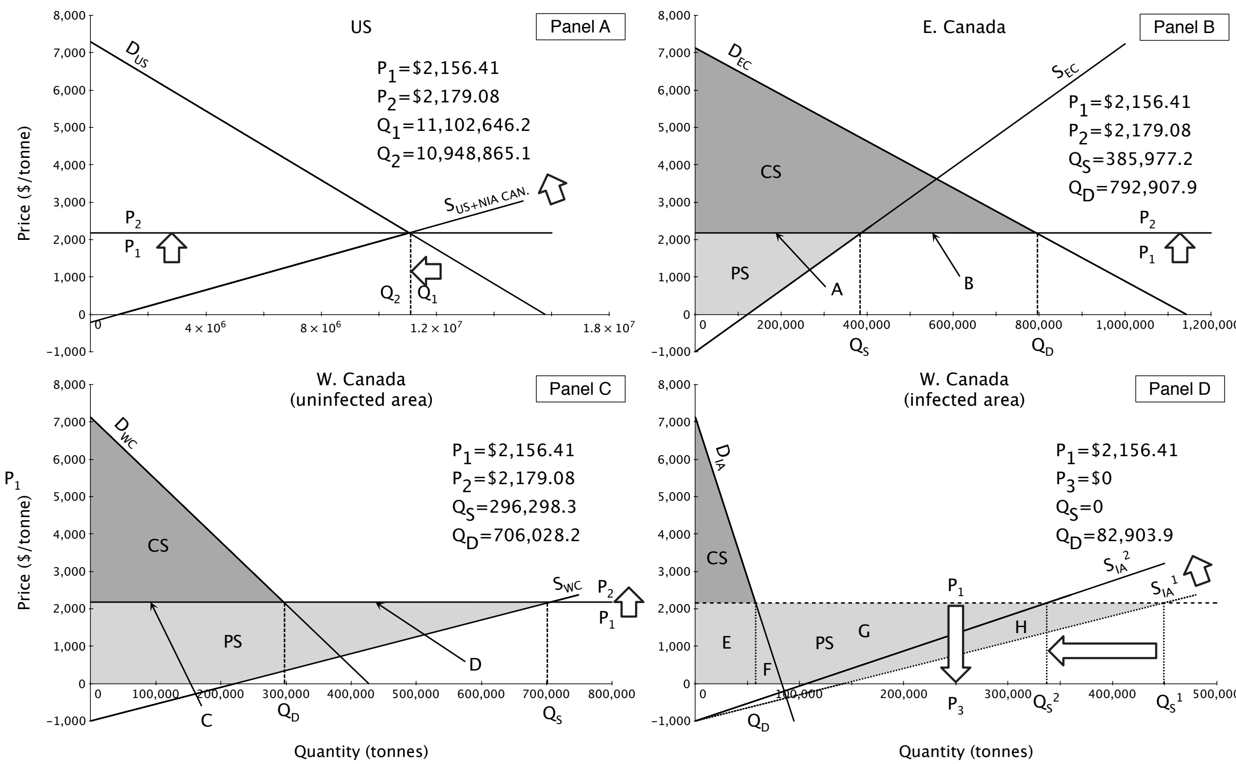


Figure 4.7: Large Outbreak Supply-Demand Curves

4.8.2 Changes from Base Case

Table 4.12 summarizes the results from the large outbreak. In the non-infected areas of Canada, consumers are paying a higher price than they were pre-outbreak and so CS decreases (see Table 4.13). PS increases as producers receive higher prices. It should be noted that these results are likely under-estimates of the true impact of an FMD outbreak in this region since any beef packing plants in the region (and which slaughter cattle from a much wider area) would also be affected.

	W. Canada (Infected)			W. Canada (Non-infected)			E. Canada		
Scen.	P	Q_D	Q_S	P	Q_D	Q_S	P	Q_D	Q_S
B.C.	2,156.41	57,813.1	449,371.1	2,156.41	297,656.6	700,994.0	2,156.41	796,542.8	383,225.1
3a	0.00	82,903.9	0.0	2,179.08	296,298.3	706,028.2	2,179.08	792,907.9	385,977.2
Δ	-2,156.41	25,090.9	-449,371.1	22.67	-1,358.3	5,034.2	22.67	-3,634.9	2,752.1

Table 4.12: Scenario 3a: Quantity change from Base Case

		Consumer Surplus (CS)		
Region	Base Case	Scenario 3a	$\Delta CS(\%)$	$\Delta CS(\$)$
W. Canada (infected)	143,627,484	295,349,239	105.6	151,721,755
W. Canada (non-infected)	739,481,264	732,747,654	-0.9	-6,733,610
E. Canada	1,978,885,808	1,960,866,360	-0.9	-18,019,449
		Producer Surplus (PS)		
Region	Base Case	Scenario 3a	$\Delta PS(\%)$	$\Delta PS(\$)$
W. Canada (infected)	638,105,118	0	-100.0	-638,105,118
W. Canada (non-infected)	995,408,706	1,011,359,980	1.6	15,951,274
E. Canada	544,178,103	552,898,475	1.6	8,720,372
		Total Surplus (TS)		
Region	Base Case	Scenario 3a	$\Delta TS(\%)$	$\Delta TS(\$)$
W. Canada (infected)	781,732,602	295,349,239	-62.2	-486,383,363
W. Canada (non-infected)	1,734,889,969	1,744,107,634	0.5	9,217,665
E. Canada	2,523,063,912	2,513,764,835	-0.4	-9,299,076

Table 4.13: Scenario 3a: Surplus Change from Base Case

4.9 Scenario 3b

In this scenario a small FMD outbreak occurs in Northern Alberta as shown in Figure 4.8. It is assumed that the region where the outbreak occurs is Census Agricultural Region (CAR) 4870 which contains 6.6% of Alberta's total cattle population (Statistics Canada, 2007). The cattle population in the region is spread out and so it is assumed that an outbreak would be contained with a small cull of 10% of the cattle population.[9] Table 4.14 shows the slaughter cattle populations before the outbreak and the number that are culled in controlling the outbreak.

CANADA, 2010	INFECTED AREA
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	62,507.1
% Culled	10.0
# Head Culled	6,250.7
REMAINING SLAUGHTER CATTLE	56,256.4

Table 4.14: Slaughter Cattle populations before and after small outbreak

[9] 10% cull assumptions based on discussion with Cheryl Waldner (DVM, PhD).

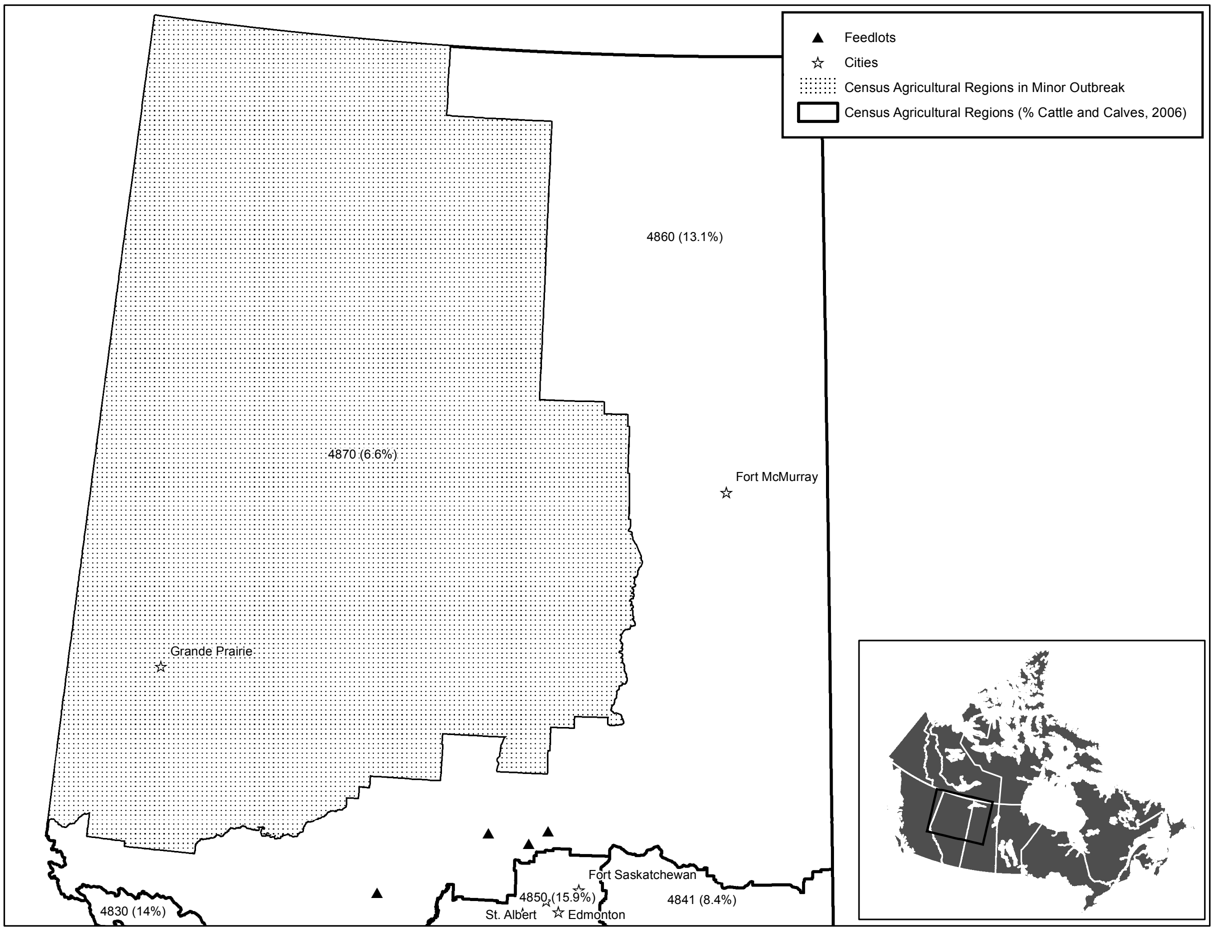


Figure 4.8: Map of Small Outbreak Location

In order to calculate the effects of the outbreak in the regions, a new base case is constructed that has the Infected Area separated from the rest of western Canada as shown in Table 4.15. The "Infected Area" column contains the data for the region where the outbreak will occur. The data was calculated by multiplying the Alberta data by the percentage cattle population of the region which is 6.6%. The "Rest of W. Canada" column is the western Canada data minus the Infected Area data. The eastern Canada data is unchanged. Supply, demand and surplus values are recalculated for comparison to the post-outbreak values.

CANADA, 2010	INFECTED AREA	REST OF W. CANADA	E. CANADA
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	62,507.1	898,244.0	346,871.4
Total Steer-Heifer Exports to US (Tonnes)	10,543.4	179,070.6	36,353.7
Beef and Veal Exports Canada to US (Tonnes)	14,455.5	205,934.6	88,396.9
TOTAL Exports (tonnes)	24,998.9	385,005.2	124,750.6
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0
Population, 2010	185,750	10,328,759	23,561,099
SUPPLY (Tonnes)	73,050.5	1,077,314.6	383,225.1
DEMAND (Tonnes)	48,051.6	692,309.4	411,651.5
WEIGHTED DEMAND (Tonnes)	6,279.8	349,189.9	796,542.8

Table 4.15: Small Outbreak Base Case Data

Once the outbreak occurs trade is cut off from the infected area. Trade both inter-provincial and with the US still occurs in eastern Canada and the Rest of western Canada. The following assumptions are made:

4.9.1 Assumptions

1. Animal traceability is utilized to minimize the spread of disease and the duration of the outbreak.

2. Infected Area slaughter cattle decreases by cull amount (10%).

3. Infected Area has the capacity to perform the 10% cull.[10]

4. Infected Area is quarantined and exports go to 0.

5. Rest of W. Canada numbers stay the same as they were before the outbreak.

6. E. Canada Supply decreases by amount not imported from Infected Area.

7. US supply decreases by amount not imported from Infected Area.

8. US P_E will change and new P_E will be used in Canada (except in the Infected Area).

9. Infected Area will trade at local equilibrium price to clear the market.

[10]This is a simplifying assumption but it is acknowledged that northern Alberta would not have the ability to covert culled animals to food inside quarantined zones.

Table 4.16 shows the new data after the outbreak occurs. Slaughter Cattle in the "Infected Area" decreases by the amount culled (10%) in order to eradicate the disease. Export values all drop to 0 as trade is halted. Measures go into effect to quarantine infected areas and animal movements outside the infected area are halted. Supply and Demand figures change accordingly based on the new data. The other columns of data are unchanged post-outbreak.

CANADA, 2010	INFECTED AREA	REST OF W. CANADA	E. CANADA
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	56,256.4	898,244.0	346,871.4
Total Steer-Heifer Exports to US (Tonnes)	0.0	179,070.6	36,353.7
Beef and Veal Exports Canada to US (Tonnes)	0.0	205,934.6	88,396.9
TOTAL Exports (tonnes)	0.0	385,005.2	124,750.6
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0
Population, 2010	185,750	10,328,759	23,561,099
SUPPLY (Tonnes)	56,256.4	1,077,314.6	383,225.1
DEMAND (Tonnes)	56,256.4	692,309.4	411,651.5
WEIGHTED DEMAND (Tonnes)	6,279.8	349,189.9	796,542.8

Table 4.16: Small Outbreak Post-Outbreak Data

Figure 4.9 shows the changes to the supply-demand curves for each of the regions and the new price lines. In the US (*Panel A*) supply shifts by the amount that was exported from the "Infected Area". This change results in a new price (P_2) of \$2,160.07. This is the price that the trading regions of Canada will also receive. The price in eastern Canada (*Panel B*) and the non-infected area of western Canada (*Panel C*) increases from P_1 to P_2. In eastern Canada CS decreases by amount $A + B$ while PS increases by amount A. In the "Infected Area" supply shifts by the amount of cattle culled. As *Panel D* shows, the equilibrium condition would result in a negative price so effectively the price drops to \$0.

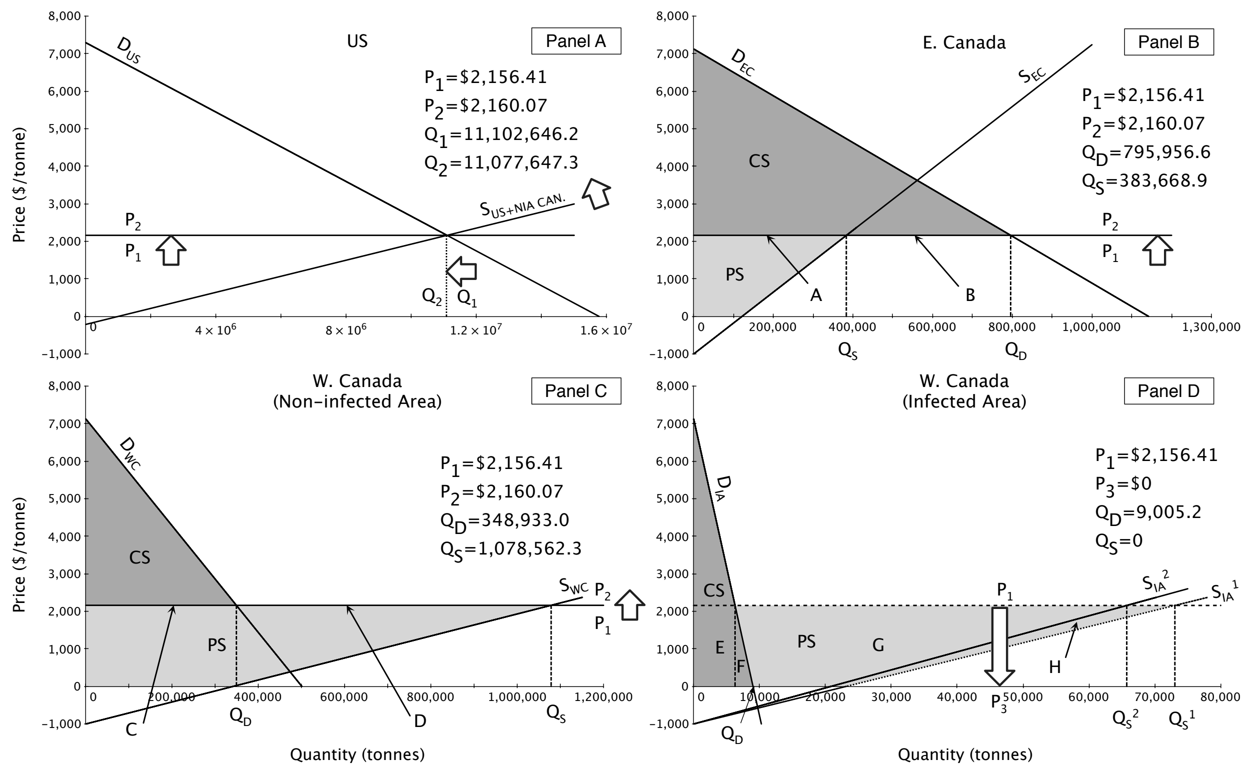


Figure 4.9: Small Outbreak Supply-Demand Curves

4.9.2 Changes from Base Case

Table 4.17 summarizes the results from the small outbreak scenario. In the non-infected areas of western Canada and eastern Canada the change is slight due to the small increase in price received. CS takes a slight hit as consumers are worse off by paying a higher price (see Table 4.18). Producers are slightly better off by receiving a higher price. The impacts are more dramatic in the infected area of western Canada. CS is much higher because of the price in the region dropping to effectively \$0.[11] PS goes down 100% in the infected area as producers are stuck with product that may need to be culled and/or sold at a great discount.

	W. Canada (Infected)			W. Canada (Non-infected)			E. Canada		
Scen.	P	Q_D	Q_S	P	Q_D	Q_S	P	Q_D	Q_S
BC	2,156.41	6,279.8	73,050.5	2,156.41	349,189.9	1,077,314.6	2,156.41	796,542.8	383,225.1
3b	0.00	9,005.2	0.00	2,160.07	348,933.0	1,078,562.3	2,160.07	795,956.6	383,668.9
Δ	-2,156.41	2,725.4	-73,050.5	3.66	-257.0	1,247.7	3.66	-586.2	443.8

Table 4.17: Scenario 3b: Quantity change from Base Case

[11] Of course in reality this may not be the case. If animals cannot move to slaughter because of quarantine zones, or lack of sufficient slaughter capacity in the region, there could be a shortage of beef pushing prices up.

		Consumer Surplus (CS)		
Region	Base Case	Scenario 3b	$\Delta CS(\%)$	$\Delta CS(\$)$
W. Canada (infected)	15,601,057	32,081,326	105.6	16,480,270
W. Canada (non-infected)	867,507,692	866,231,317	-0.1	-1,276,375
E. Canada	1,978,885,808	1,975,974,250	-0.1	-2,911,559
		Producer Surplus (PS)		
Region	Base Case	Scenario 3b	$\Delta PS(\%)$	$\Delta PS(\$)$
W. Canada (infected)	103,731,374	0	-100.0	-103,731,374
W. Canada (non-infected)	1,529,782,449	1,533,724,028	0.3	3,941,579
E. Canada	544,178,103	545,580,212	0.3	1,402,108
		Total Surplus (TS)		
Region	Base Case	Scenario 3b	$\Delta TS(\%)$	$\Delta TS(\$)$
W. Canada (infected)	119,332,430	32,081,326	-73.1	-87,251,104
W. Canada (non-infected)	2,397,290,141	2,399,955,345	0.1	2,665,204
E. Canada	2,523,063,912	2,521,554,462	-0.1	-1,509,450

Table 4.18: Scenario 3b: Surplus Change from Base Case

4.10 Compensation for Producers

The results from Scenario 3a and 3b show that producers in the Infected Area are greatly impacted by the loss in surplus resulting from the collapse of prices in the region. Therefore producers [12] will be tempted to smuggle their animals to the non-infected regions in order to get higher prices. As was discussed previously, animal movement tracking in regions like West Hawk Lake could be highly effective in making smuggling difficult. This will not, however, help in the situation where a producer is trying to move an animal in an area with multiple roadways and no geographic boundaries to prevent movement. In this case a policy instrument will be needed to remove the incentive to smuggle.

If producers in the Infected Areas received the same prices that producers in the Non-Infected Areas did there would be no incentive to smuggle. This compensation would need to be provided by the government. In this section the compensation amount will be calculated for the outbreak scenarios modelled previously.

Figure 4.10 shows the graph for Supply/Demand in the Infected Area under the large outbreak scenario. The price line shows the price \$2,179.08 which is the same price as the rest of Canada receives. The price line intersects the supply curve S_{IA}. The quantity supplied at that price (Q_S) does not intersect the demand curve in positive price space and therefore price P_2 must be paid for each unit produced between 0 and Q_D.

[12] Or others that can acquire animals at the low price in the infected area and then smuggle them to the disease-free area where higher prices prevail.

This works out to \$986,249,452 and is shown by the grey shaded box labelled 'COMPENSATION'.

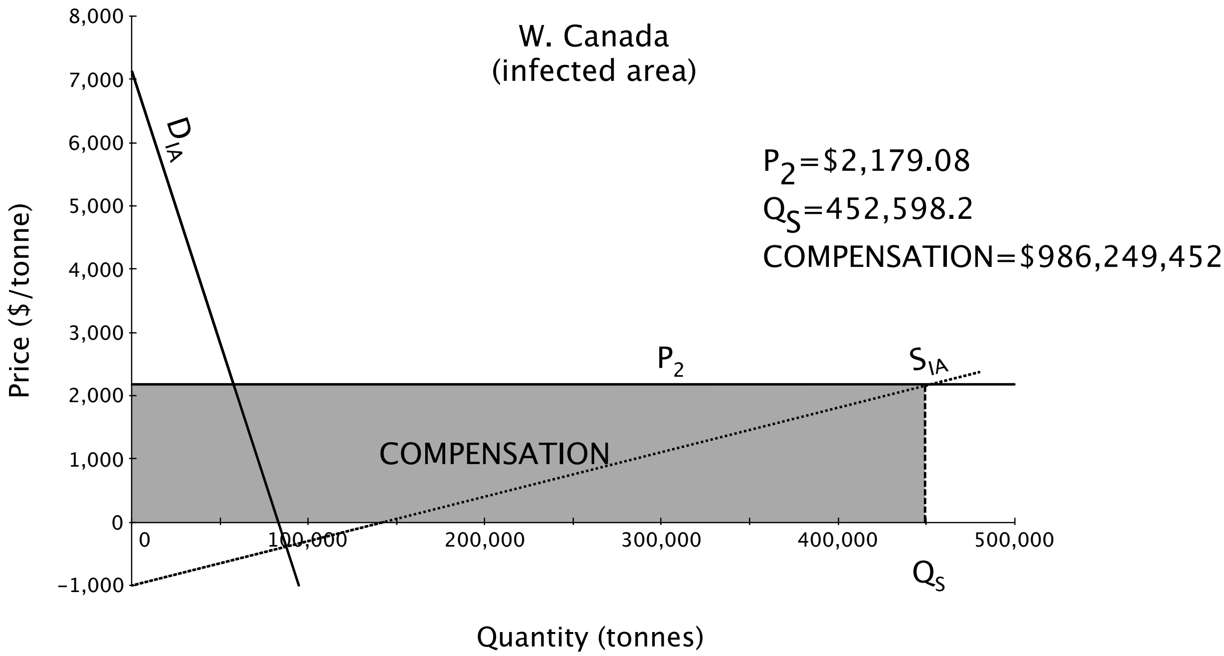


Figure 4.10: Large Outbreak With Compensation

Figure 4.11 shows the graph for Supply/Demand in the Infected Area under the small outbreak scenario. The price line shows the price \$2,160.07 which is the same price as the rest of Canada receives. The price line intersects the supply curve S_{IA}. The quantity supplied at that price (Q_S) does not intersect the demand curve in positive price space and therefore price P_2 must be paid for each unit produced between 0 and Q_D. This works out to \$157,976,629 and is shown by the grey shaded box labelled 'COMPENSATION'.

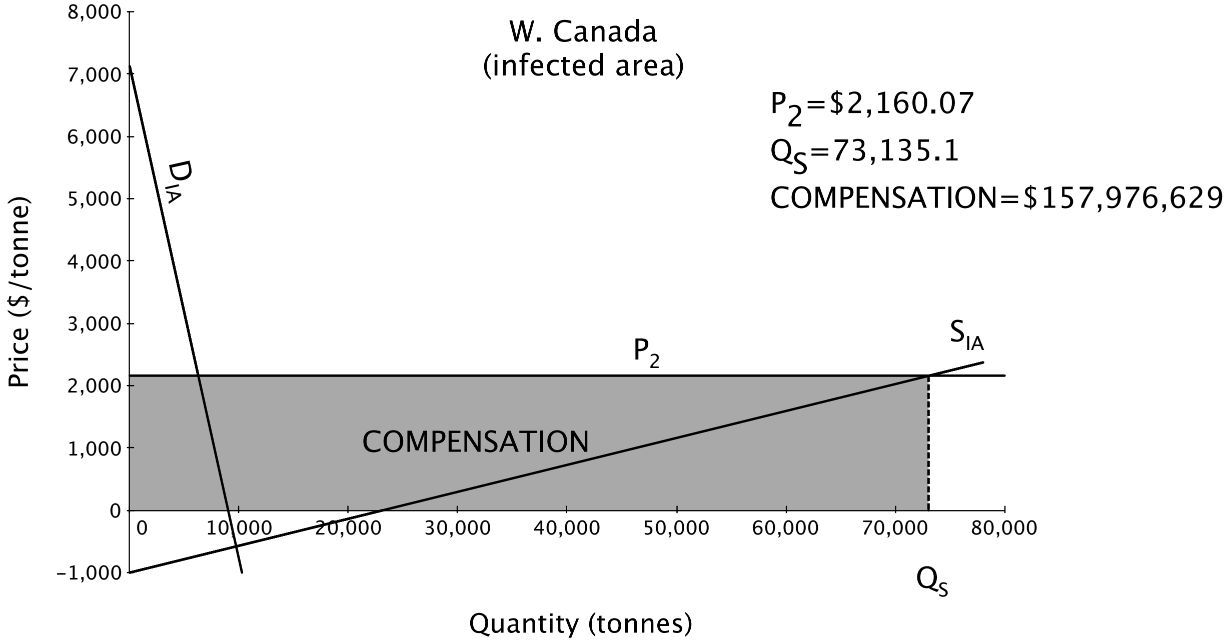


Figure 4.11: Small Outbreak With Compensation

4.11 Final Results

Table 4.19 summarizes the results for all scenarios. The highest and lowest values in each column are indicated by bold typeface. The next sections will talk about the largest increases and decrease in all surplus measures. Percentage changes (%) refer to the percent change in the surplus between the base case and the scenario. Absolute changes ($) refer to the dollar amount change from the base case to the scenario.

4.11.1 Consumer Surplus (CS)

The largest decrease in CS in percentage terms occurs in scenario 2 where trade is allowed with eastern Canada only. In eastern Canada the CS decreased the most in percentage terms as well as in absolute terms. Since demand remains constant in all scenarios, a decrease in CS is caused by a rise in price which translates into a smaller area between the demand curve and price line. Trade between eastern Canada and the US results in the highest prices for eastern Canada.

The largest increase in CS in percentage terms is in the infected area of western Canada during an

	REGION	ΔCS(%)	ΔPS(%)	ΔTS(%)	ΔCS($)	ΔPS($)	ΔTS($)
S1	W.Can.	22.5	-34.3	-14.3	199,135,482	-560,194,297	-361,058,815
	E.Can.	22.5	-34.3	10.3	446,226,335	-186,619,461	**259,606,873**
S2	W.Can.	86.9	-91.3	-28.8	**767,183,948**	**-1,491,963,354**	**-724,779,406**
	E.Can.	**-3.2**	**5.8**	-1.3	**-63,805,780**	**31,344,974**	-32,460,806
S3a	W.Can.(IA)	**105.6**	**-100.0**	-62.2	151,721,755	-638,105,118	-486,383,363
	W.Can.(NIA)	-0.9	1.6	0.5	-6,733,610	15,951,274	9,217,665
	E.Can.	-0.9	1.6	-0.4	-18,019,449	8,720,372	-9,299,076
S3b	W.Can.(IA)	**105.6**	**-100.0**	**-73.1**	16,480,270	-103,731,374	-87,251,104
	W.Can.(NIA)	-0.1	0.3	0.1	-1,276,375	3,941,579	2,665,204
	E.Can.	-0.1	0.3	-0.1	-2,911,559	1,402,108	-1,509,450
S3a	**W.Can.(IAC)**	**105.6**	1.6	**20.7**	151,721,755	10,225,538	161,947,293
	W.Can.(NIA)	-0.9	1.6	0.5	-6,733,610	15,951,274	9,217,665
	E.Can.	-0.9	1.6	-0.4	-18,019,449	8,720,372	-9,299,076
S3b	**W.Can.(IAC)**	**105.6**	0.3	14.0	16,480,270	267,270	16,747,540
	W.Can.(NIA)	-0.1	0.3	0.1	-1,276,375	3,941,579	2,665,204
	E.Can.	-0.1	0.3	-0.1	-2,911,559	1,402,108	-1,509,450

Table 4.19: Change in Surplus Summary

outbreak with or without compensation (scenarios 3a and 3b). In the infected areas there is no trade occurring and prices collapse. This large decrease in price causes CS to increase. In absolute terms, CS increases the most in scenario 2 in western Canada. With trade cut off from the US prices decrease and a larger number of consumers in western Canada benefit as opposed to the infected areas in scenarios 3a and 3b where populations are smaller.

These scenarios make a simplifying assumption that cattle from non-quarantined farms/feedlots can still move to packing plants for slaughter to produce beef for that region.

4.11.2 Producer Surplus (PS)

The largest decrease in PS in percentage terms occurs in the infected areas of western Canada in scenarios 3a and 3b. The cut off from trade for the region results in the price crashing such that PS is essentially 0. This is the opposite of what happens to CS which is highest in these scenarios. In absolute terms PS decreases the most in western Canada during scenario 2, where trade occurs only with eastern Canada. With trade cut off from the US, prices decrease for all of western Canada and a larger population of producers is worse off from the lower prices. On the other hand CS is highest in this scenario.

The largest increase in PS in percentage terms and absolute terms is in eastern Canada in scenario 2. With trade between the US and eastern Canada only prices rise causing an increase in PS for the whole population. This is also the scenario where CS decrease the most in percentage and absolute terms.

4.11.3 Total Surplus (TS)

The largest decrease in TS in percentage terms occurs in the infected area of western Canada in the small outbreak. Although percentage increase CS is largest here it is overwhelmed by the decrease in PS which explains why TS experiences such a large percentage decline. The second largest decrease in TS is in the same region in the large outbreak. The largest decrease in TS in absolute terms occurs in western Canada in scenario 2, where trade occurs only with eastern Canada. While CS is the highest here it is overwhelmed by the decrease in PS in western Canada. In fact in western Canada in scenario 2, CS has the highest increase and PS the highest decrease in absolute terms.

The largest increase in TS in percentage terms occurs in the infected area of western Canada in the large outbreak where compensation is given to producers. This is due to the large change in CS when prices collapse but producers are also compensated such that PS does not change as much as when compensation is not provided. The largest increase in TS in absolute terms is in eastern Canada in scenario 1 when there is no trade with the US. Consumers benefit more from the lower prices than producers due to the smaller supplies found in the east.

4.11.4 Surplus changes under Compensation

The last two sections of Table 4.19 (beneath the double line) show the changes in surplus in scenarios 3a and 3b when the producers in the infected areas are compensated at market prices (designated as W.Can(IAC)). This compensation eliminates the incentive for producers to smuggle their animals to regions with higher prices. The effects of surplus change in the non-infected areas (W.Can.(NIA)) and eastern Canada (E.Can.) are exactly the same as the previous scenarios without compensation. The changes are only felt in the infected areas where supply and demand remain the same and price changes to the price the rest of Canada receives.

In the infected areas without compensation, the change to CS, PS and TS was quite high due to the collapse in price. CS increased greatly with the low price and PS decreased completely. Under compensation the effects in the infected area were mitigated. Compensation resulted in a slightly higher price making producers better off. The compensation does not affect consumers so they are better off with or without compensation because of the collapse in price. Without compensation, change in TS was negative but under compensation it was positive. Therefore the conclusion would seem to be that compensation made everyone better off. However, the amount of compensation has not been taken into account. This cost needs to be added to the results in order to fully determine if compensation is a benefit or a liability. Compensation is paid by the federal government which comes out of taxes which are borne by all citizens.

4.12 Sensitivity Analysis

A sensitivity analysis was performed to determine how sensitive are the results to key assumptions, namely elasticities. Elasticity values were changed by 10% in the sensitivity analysis. Table 4.20 shows the results of all scenarios with demand and supply elasticities changed by 10%. The percent change in CS and PS is recalculated with each new elasticity value. The new values are compared to the unchanged values by finding their percent change. Only one value is changed at a time.

Changing the demand elasticity will affect CS because CS is measured with the demand curve. Similarly changing the supply elasticity affects PS. The results are more sensitive to the change in the demand elasticity as increasing or decreasing this elasticity by 10% resulted in the biggest changes to CS as seen in the results in scenarios 3a and 3b in the infected area. Increasing the demand elasticity by 10% resulted in increases in the change of CS and decreasing it by 10% resulted in the biggest decreases. These numbers are indicated by * in Table 4.20. The results show that the effects of changing the supply elasticity on PS were smaller compared to the demand elasticity changes.

From these results it would seem that the analysis is more sensitive to change in the demand elasticity than the supply elasticity. Hence, the results based on estimates of demand elasticity should be interpreted with care. The supply elasticity should also be carefully chosen but it may not be as critical to results as the demand elasticity. Overall, the results are reasonably robust to changes in the demand and supply elasticity values.

Change	Region	Scenario 1 No Trade ΔCS	 ΔPS	Scenario 2 Trade w E. Canada ΔCS	 ΔPS	Scenario 3b Small Outbreak ΔCS	 ΔPS	Scenario 3a Large Outbreak ΔCS	 ΔPS
None	W.Can.(IA)	n/a	n/a	n/a	n/a	105.6	-100.0	105.6	-100.0
	W.Can.(NIA)	22.5	-34.3	86.9	-91.3	-0.1	0.3	-0.9	1.6
	E.Can.	22.5	-34.3	-3.2	5.8	-0.1	0.3	-0.9	1.6
$E_D + 10\%$	W.Can.(IA)	n/a	n/a	n/a	n/a	118.3	-100.0	118.3	-100.0
	W.Can.(NIA)	24.9	-34.3	97.0	-91.3	-0.2	0.3	-1.0	1.6
	E.Can.	24.9	-34.3	-3.5	5.8	-0.2	0.3	-1.0	1.6
% Change	W.Can.(IA)	n/a	n/a	n/a	n/a	**12.0***	0.0	**12.0***	0.0
	W.Can.(NIA)	10.6	0.0	11.7	0.0	10.0	0.0	10.0	0.0
	E.Can.	10.6	0.0	9.9	0.0	10.0	0.0	10.0	0.0
None	W.Can.(IA)	n/a	n/a	n/a	n/a	105.6	-100.0	105.6	-100.0
	W.Can.(NIA)	22.5	-34.3	86.9	-91.3	-0.1	0.3	-0.9	1.6
	E.Can.	22.5	-34.3	-3.2	5.8	-0.1	0.3	-0.9	1.6
$E_D - 10\%$	W.Can.(IA)	n/a	n/a	n/a	n/a	93.4	-100.0	93.4	-100.0
	W.Can.(NIA)	20.2	-34.3	77.0	-91.3	-0.1	0.3	-0.8	1.6
	E.Can.	20.2	-34.3	-2.9	5.8	-0.1	0.3	-0.8	1.6
% Change	W.Can.(IA)	n/a	n/a	n/a	n/a	**-11.6***	0.0	**-11.6***	0.0
	W.Can.(NIA)	-10.5	0.0	-11.4	0.0	-10.0	0.0	-10.0	0.0
	E.Can.	-10.5	0.0	-9.9	0.0	-10.0	0.0	-10.0	0.0
None	W.Can.(IA)	n/a	n/a	n/a	n/a	105.6	-100.0	105.6	-100.0
	W.Can.(NIA)	22.5	-34.3	86.9	-91.3	-0.1	0.3	-0.9	1.6
	E.Can.	22.5	-34.3	-3.2	5.8	-0.1	0.3	-0.9	1.6
$E_S + 10\%$	W.Can.(IA)	n/a	n/a	n/a	n/a	105.6	-100.0	105.6	-100.0
	W.Can.(NIA)	22.5	-35.8	86.9	-92.4	-0.1	0.3	-0.9	1.7
	E.Can.	22.5	-35.8	-3.2	6.1	-0.1	0.3	-0.9	1.7
% Change	W.Can.(IA)	n/a	n/a	n/a	n/a	0.0	0.0	0.0	0.0
	W.Can.(NIA)	0.0	4.5	0.0	1.2	0.0	5.5	0.0	5.5
	E.Can.	0.0	4.5	0.0	5.6	0.0	5.5	0.0	5.5
None	W.Can.(IA)	n/a	n/a	n/a	n/a	105.6	-100.0	105.6	-100.0
	W.Can.(NIA)	22.5	-34.3	86.9	-91.3	-0.1	0.3	-0.9	1.6
	E.Can.	22.5	-34.3	-3.2	5.8	-0.1	0.3	-0.9	1.6
$E_S - 10\%$	W.Can.(IA)	n/a	n/a	n/a	n/a	105.6	-100.0	105.6	-100.0
	W.Can.(NIA)	22.5	-32.9	86.9	-90.4	-0.1	0.2	-0.9	1.5
	E.Can.	22.5	-32.9	-3.2	5.5	-0.1	0.2	-0.9	1.5
% Change	W.Can.(IA)	n/a	n/a	n/a	n/a	0.0	0.0	0.0	0.0
	W.Can.(NIA)	0.0	-4.1	0.0	-1.1	0.0	-4.9	0.0	-5.0
	E.Can.	0.0	-4.1	0.0	-5.1	0.0	-4.9	0.0	-5.0

Table 4.20: Sensitivity Analysis

(* indicates numbers with the largest change)

4.13 Concluding remarks

This chapter discussed how the analysis was performed and the results that were found in each scenario. The results were discussed and a sensitivity analysis was performed to test the elasticity values that were used. The next chapter offers conclusions and discussion of policy implications based on these results.

Chapter 5

Conclusions and Policy Implications

This chapter begins with a review of the research question being examined, followed by a discussion of the results. Conclusions and suggested policy responses follow. The chapter concludes with limitations of the study and suggestions for future research on this topic.

5.1 Research Question

This thesis examined the impact of an FMD outbreak on Canadian beef producers and consumers with respect to access to export markets. It looked at different scenarios ranging from zero trade to partial trade from non-infected areas of Canada. The impacts of a regionalization policy were examined by measuring the effect on consumer and producer surplus under the different degrees of trade restriction compared to a base case. If economic welfare losses under partial trade conditions are lower, arguments can be made for policies that allow regionalization including potential benefits of a national traceability system. The potential for compensation policies to facilitate regionalization through limiting incentives for smuggling are also discussed.

5.2 Discussion of Results

In terms of a price change, when the price decreases consumers are better off while producers are worse off, providing supply and demand remain the same. Logically this makes sense because consumers would rather pay less for a product, ceteris paribus. At a lower price producers are making less money per unit sold so they are worse off. In terms of the graphs, when price decreases the price line shifts downward creating a larger consumer surplus (the area between the demand curve and the price line) and a smaller producer surplus (the area between the price line and the supply curve). All of this is reversed when price increases.

In addition to looking at the changes to CS and PS, the change in Total Surplus (TS) was also examined. TS is the sum of CS and PS which shows the overall change in surplus. If TS increases then society is better off overall even though it could mean that CS or PS has decreased, meaning different distributional outcomes under different scenarios.

The following sections summarize key results under the modelling scenarios.

5.2.1 Scenario 1 - No Trade

In Scenario 1 there is no trade with the US during an FMD outbreak (Figure 5.1). This is the situation that Canada would face today without a regionalization policy. The closing of the US border to beef and cattle trade resulted in a lower price in Canada as price goes to the domestic equilibrium. With supply and demand unchanged, a decrease in price results in a higher CS and a lower PS. The overall effect measured with TS showed a decline in western Canada and an increase in eastern Canada.

To see the effects of scenario 1 on Canada as a whole, the surplus values for east and west are summed in Table 5.1. The increase in surplus that consumers achieve from a lower price is less than the decrease in surplus for producers. The overall change in surplus for Canada is -\$101,451,941 which leads to the conclusion that, on the whole, Canadians are worse off in the absence of trade, and the negative impact on the beef sector is significant.

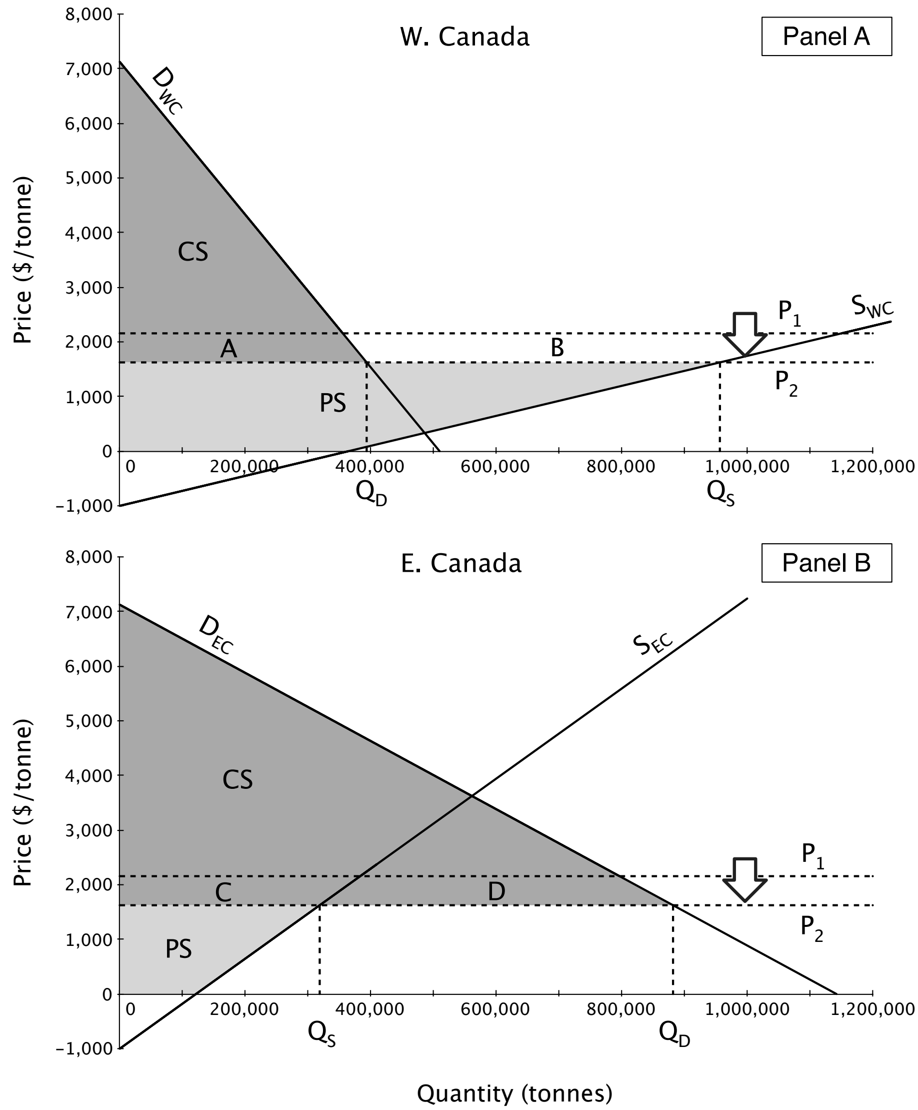


Figure 5.1: Scenario 1: No Trade

REGION	$\Delta CS(\$)$	$\Delta PS(\$)$	$\Delta TS(\$)$
W. CAN.	$199,135,482	-$560,194,297	-$361,058,815
E. CAN.	$446,226,335	-$186,619,461	$259,606,873
TOTAL	**$645,361,817**	**-$746,813,758**	**-$101,451,941**

Table 5.1: Scenario 1: No Trade

5.2.2 Scenario 2 - Exports from Eastern Canada Only

In Scenario 2, exports are only allowed from eastern Canada during an FMD outbreak in western Canada (Figure 5.2). Animal movement monitoring at West Hawk Lake prevents all animal movements from west to east, ensuring the US that FMD will not spread to eastern Canada where exports continue. With exports closed to western Canada, supply decreases in the US resulting in a higher US (ROW) price. This new US price is also the price received in eastern Canada, since the US represents the "Rest of the World" in this analysis. The market in western Canada moves to regional equilibrium resulting in a much lower price than the price received under trade. In eastern Canada the new price is slightly higher resulting in a decrease in CS and an increase in PS.

According to Table 5.2, western Canada has a very high increase in CS while eastern Canada sees a smaller decrease from the price changes. Conversely, western Canada has a very high decrease in PS while eastern Canada has a small increase. TS is down -\$724,779,406 in western Canada and -\$32,460,806 in eastern Canada. Overall TS is down -\$757,240,212 for the whole country. Canada is much worse off in scenario 2 with partial trade than it was in scenario 1 under the total absence of trade (Table 5.1).

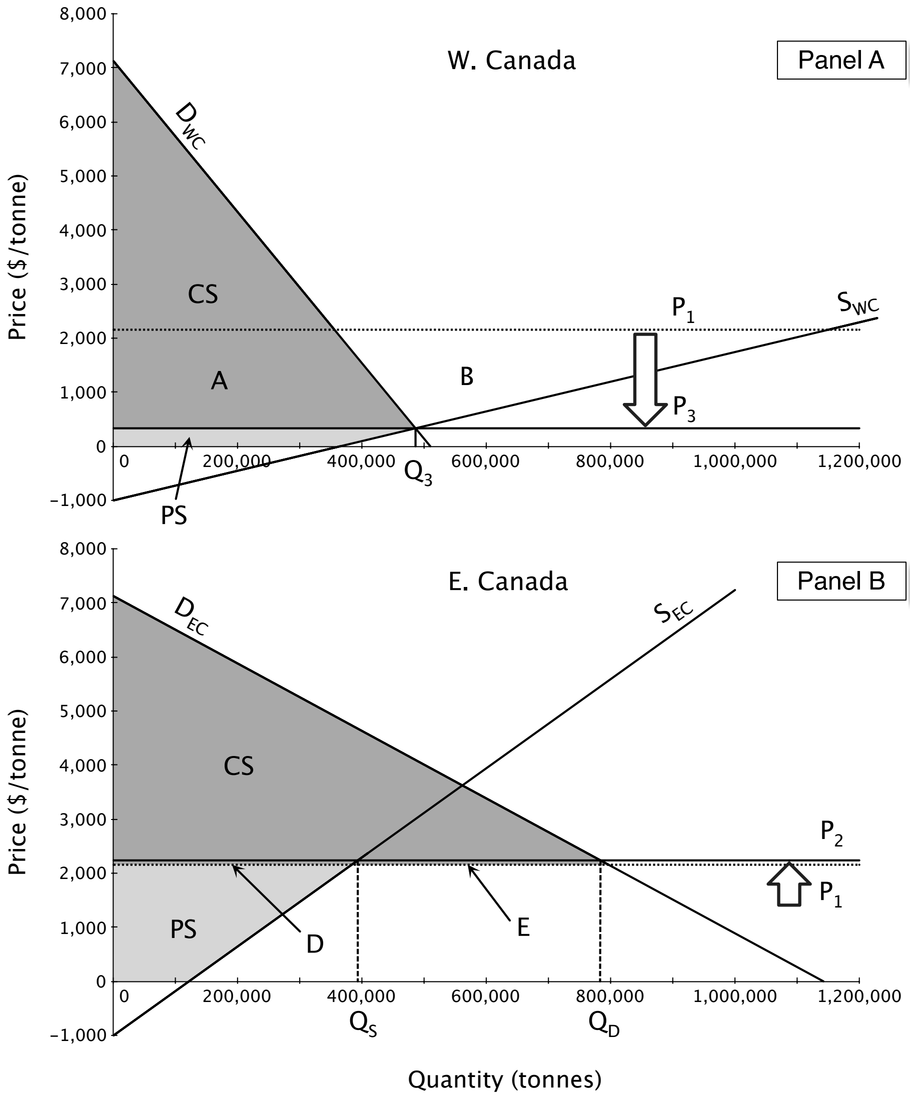


Figure 5.2: Scenario 2: Trade With Eastern Canada Only

REGION	ΔCS($)	ΔPS($)	ΔTS($)
W. CAN.	$767,183,948	-$1,491,963,354	-$724,779,406
E. CAN.	-$63,805,780	$31,344,974	-$32,460,806
TOTAL	**$703,378,168**	**-$1,460,618,380**	**-$757,240,212**

Table 5.2: Scenario 2: Trade With Eastern Canada Only

In scenario 2, western Canada bears the consequences of the FMD outbreak by being cut off from trade. Since western Canada is such a large producer of livestock[1], the decrease in surplus greatly overshadows the benefits eastern Canada gets from trade. In scenario 1 the whole country is cut off from trade but

[1]Recall western Canada supplies itself in addition to exporting to eastern Canada and the US.

inter-regional trading still occurs from west to east and the whole country shares the same price.

If the roles were reversed, in which an outbreak occurred in eastern Canada and trade was allowed from western Canada, the TS decline would be much smaller because eastern Canada is a net importer of beef. The surplus benefits that the west achieves would most likely overshadow the decrease in surplus in the east. This could be a subject for future study. The results suggest that a "regionalization policy" would only be effective at reducing losses if it could be targeted more precisely at affected regions and depending on the relative importance of the affected region in beef production.

5.2.3 Scenario 3a - Large Outbreak - Trade with Non-infected Area

In Scenario 3a an FMD outbreak occurs in central Alberta where cattle populations are high and dense. The outbreak is brought under control with a 25% cull of livestock. Trade with the US continues with eastern Canada and the non-infected regions of western Canada. Supply in the US decreases slightly due to a ban on imports from the infected area of western Canada. The US price rises slightly and this price is received in eastern Canada and the non-infected areas of western Canada. The infected area is closed to trade and prices collapse because equilibrium occurs when price is less than 0 (Figure 5.3).

The higher US price used in the rest of Canada causes CS to decrease and PS to increase (Table 5.3). But since the change in price is slight the changes in surplus are also slight compared to the changes in the infected area. TS increases in the non-infected areas that are trading with the US but TS is significantly decreased in the infected area. The overall change in TS for the country is -\$486,464,774 which is the second worst outcome of all the scenarios. The only worse outcome was from Scenario 2 with -\$757,240,212.

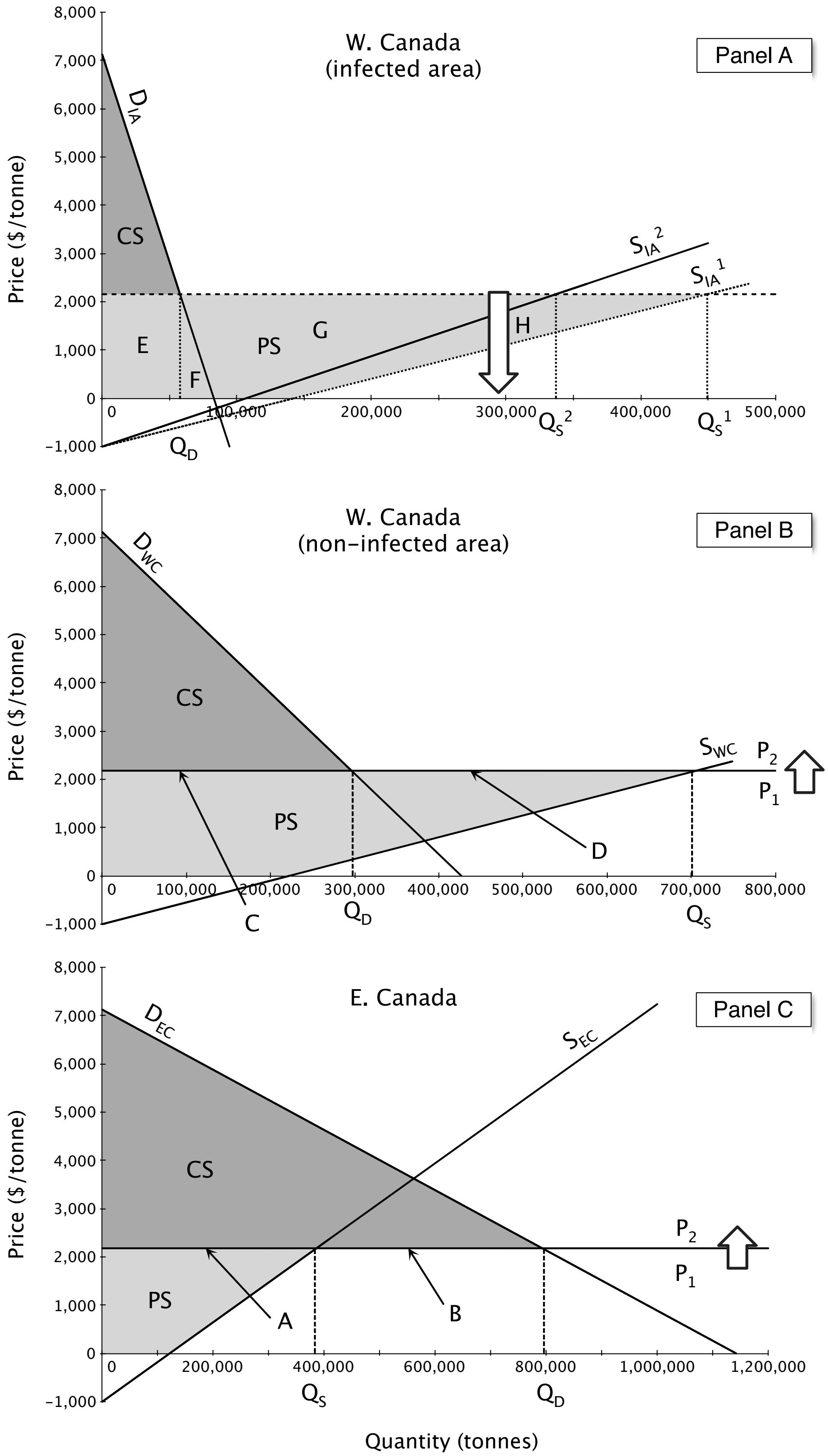


Figure 5.3: Scenario 3a: Large Outbreak - Trade With Non-infected Canada Only

REGION	ΔCS($)	ΔPS($)	ΔTS($)
W. CAN. (IA)	$151,721,755	-$638,105,118	-$486,383,363
W. CAN. (NIA)	-$6,733,610	$15,951,274	$9,217,665
E. CAN.	-$18,019,449	$8,720,372	-$9,299,076
TOTAL	**$126,968,697**	**-$613,433,471**	**-$486,464,774**

Table 5.3: Scenario 3a: Large Outbreak - Trade With Non-infected Canada Only

Whereas the small outbreak result from Scenario 3b was the best of all outcomes, this scenario is almost the worst. In fact the full trade loss outcome of Scenario 1 had a better outcome (-$101,451,941) than this scenario, again because under scenario 1 inter-regional trade is still possible within Canada.

The outcomes show that a larger outbreak in western Canada translates into a higher overall decrease in TS for the country. Any gains in surplus from the trading regions are greatly offset by the losses in the infected areas. As western Canada produces so much of the supply of livestock, the losses due to FMD outbreaks are high. If the outbreaks occurred in a region of eastern Canada the story could be quite different. This scenario is, however, likely unsustainable due to the price difference between the infected area and the non-infected area in western Canada. This price difference creates a large incentive to smuggle. As even a few animals being successfully smuggled would lead to the spread of the disease to the non-infected area and the loss of its ability to export.

5.2.4 Scenario 3b - Small Outbreak - Trade with Non-infected Area

In Scenario 3b an FMD outbreak occurs in northern Alberta where cattle populations are thin. The outbreak is brought under control with a 10% cull of livestock. Trade with the US continues with eastern Canada and the non-infected regions of western Canada. Supply in the US decreases slightly due to a ban on imports from the infected area of western Canada. The US price rises slightly and this price is received in eastern Canada and the non-infected areas of western Canada. The infected area is closed to trade and to all livestock movements, and prices collapse because equilibrium occurs when price is less than 0 (Figure 5.4).

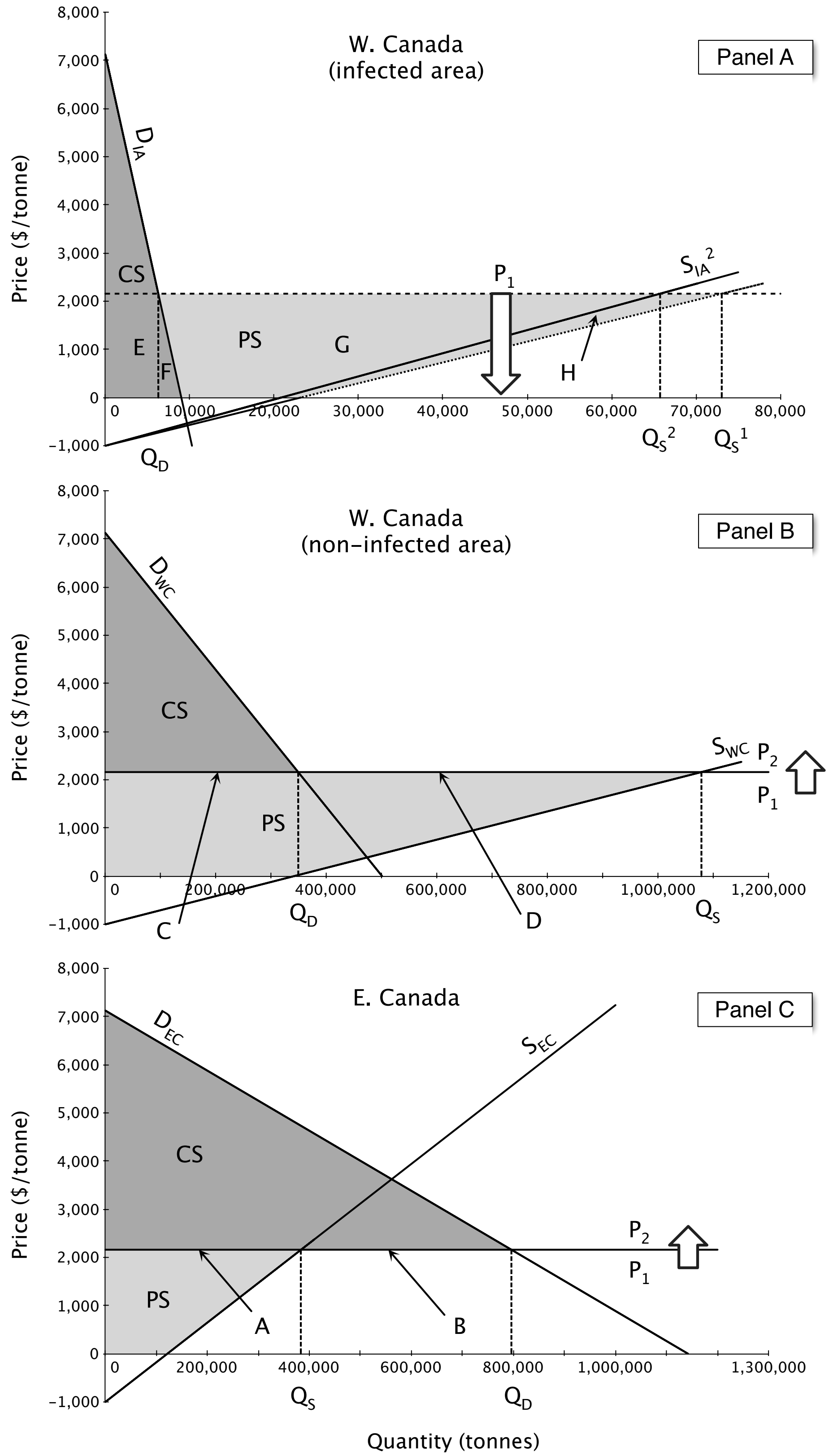


Figure 5.4: Scenario 3b: Small Outbreak - Trade With Non-infected Canada Only

The higher US (ROW) price used in the rest of Canada causes CS to decrease and PS to increase (Table 5.4). As the change in price is slight the changes in surplus are also slight compared to the changes in the infected area. TS increases in the non-infected areas that are trading with the US but TS is significantly decreased in the infected area. The overall change in TS for the country is -\$86,095,350 which is better than the outcome in Scenario 1 (-\$101,451,941) and significantly better than the outcome in Scenario 2 (-\$757,240,212).

REGION	ΔCS(\$)	ΔPS(\$)	ΔTS(\$)
W. CAN.(IA)	\$16,480,270	-\$103,731,374	-\$87,251,104
W. CAN.(NIA)	-\$1,276,375	\$3,941,579	\$2,665,204
E. CAN.	-\$2,911,559	\$1,402,108	-\$1,509,450
TOTAL	**\$12,292,337**	**-\$98,387,686**	**-\$86,095,350**

Table 5.4: Scenario 3b: Small Outbreak - Trade With Non-infected Canada Only

Whereas partial trade with the US in Scenario 2 has a poor overall outcome for Canada, the partial trade Scenario 3b has a relatively good outcome. The only way this would work would be if there was a full livestock traceability system in Canada that would quickly stop the spread of disease and the incentives to smuggle were eliminated. As there is no compensation in this scenario, the incentive to smuggle remains and if only a few animals are moved out of the region, then it is likely that the disease will spread to the non-infected area leading to its loss of export status. Regionalization would be a failed policy.

5.2.5 Scenario 3a - Large Outbreak - Compensation in Infected Area

This is Scenario 3a once more with the difference being that the producers in the infected area are compensated for their product at the same price that the rest of Canadian producers receive. Since producers are receiving the same price as the rest of Canada there is no incentive to smuggle their animals to other regions and the risk of disease spread by illegal animal movement is eliminated (or at least significantly reduced). Figure 5.5 shows the changes in the graphs from the original Scenario 3a.

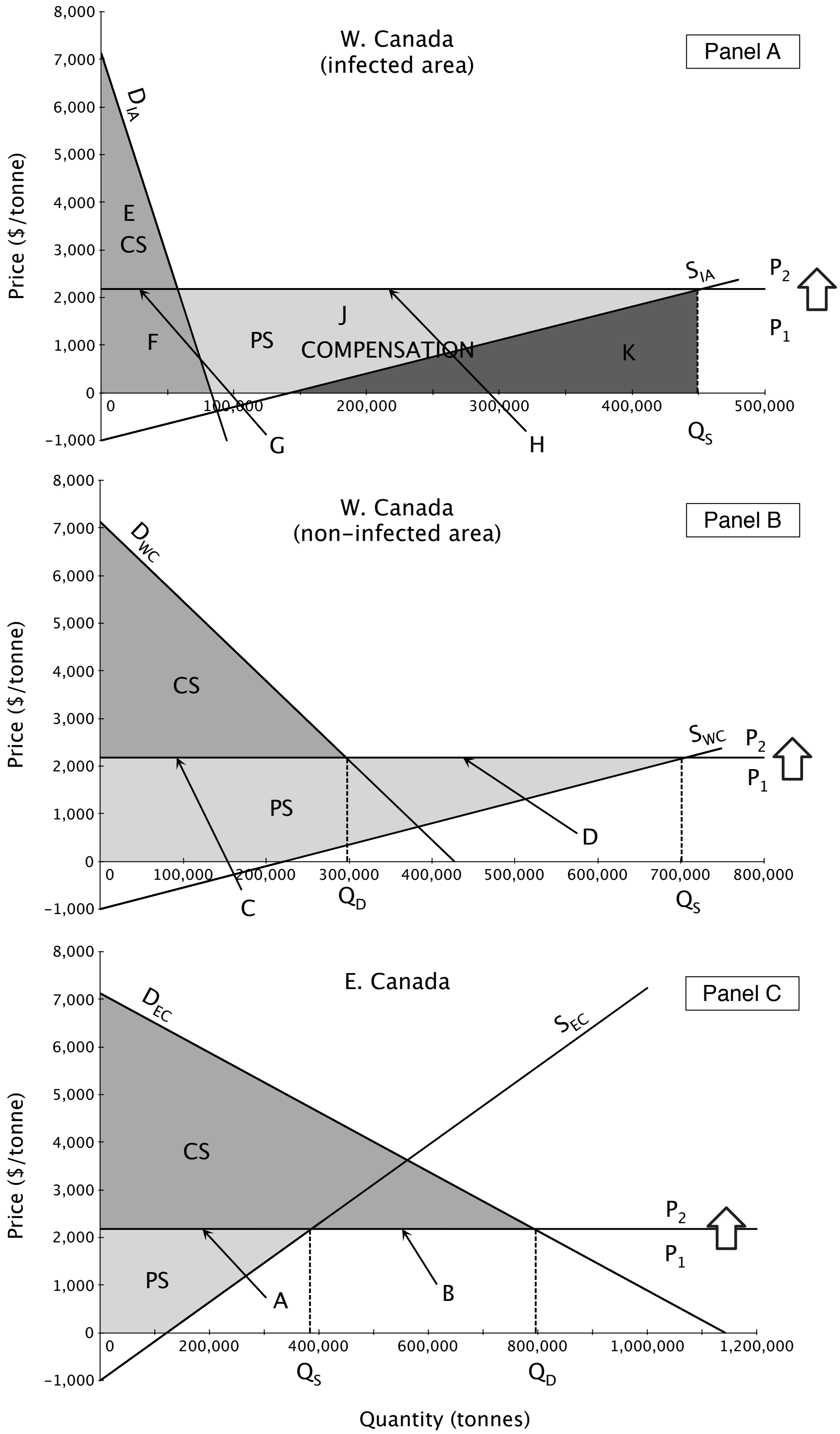


Figure 5.5: Scenario 3a: Large Outbreak - Compensation in Infected Area

Panels B and C are identical to the original panels from Scenario 3a. *Panel A* is where the change is found. Price increases to the new price P_2 which causes an increase in PS by amount $G + H$. Despite compensation being paid to producers, prices still collapse which causes CS to increase from E to $E + F$. The rectangular area labelled 'COMPENSATION' is shown shaded in dark-grey and partially obscured by the PS region. The compensation amount is the area of the rectangle from 0 to Q_S at a height of price P_2. In terms of the diagram it is the sum of areas $F + J + K$. This is the difference in the amount of animals supplied which are paid for through the compensation amount calculated as $986,249,452.

Table 5.5 shows the totals when the change in CS, PS and TS are added up for all regions. Without compensation ΔTS was -$486,464,774 and with compensation it is positive at $161,865,882. However, when the amount of compensation is included in this total the news is not as good. The amount spent on compensation for producers is -$986,249,452 which is borne by all. Adding this value to ΔTS we get a new total of -$824,383,570 which is nearly 70% higher than the non-compensated value.

The purpose of compensation is to deter smuggling and maintain the integrity of a regionalization policy, therefore allowing trade to continue from other parts of the country. However, comparing the economic cost (total surplus changes plus compensation) under scenario 3a with compensation, with scenario 1 (no trade), it is clear that regionalization with compensation is not an optimal policy in this case. Overall costs are lower in the No Trade case. In this scenario the market in the infected region completely collapses, with prices falling to zero. In reality of course other policies would need to be implemented to ensure that the market for beef in an infected region did not completely collapse.

REGION	ΔCS($)	ΔPS($)	ΔTS($)
W.CAN.(IAC)	$151,721,755	$10,225,538	$161,947,293
W.CAN.(NIA)	-$6,733,610	$15,951,274	$9,217,665
E.CAN.	-$18,019,449	$8,720,372	-$9,299,076
TOTAL	**$126,968,697**	**$34,897,185**	**$161,865,882**
		COMPENSATION	**-$986,249,452**
		TOTAL	**-$824,383,570**

Table 5.5: Scenario 3a: Large Outbreak - Compensation in Infected Area

5.2.6 Scenario 3b - Small Outbreak - Compensation in Infected Area

This is Scenario 3b once more with the difference being that the producers in the infected area are compensated for their product at the same price that the rest of Canadian producers receive. Figure 5.6 shows the changes in the graphs from the original Scenario 3b.

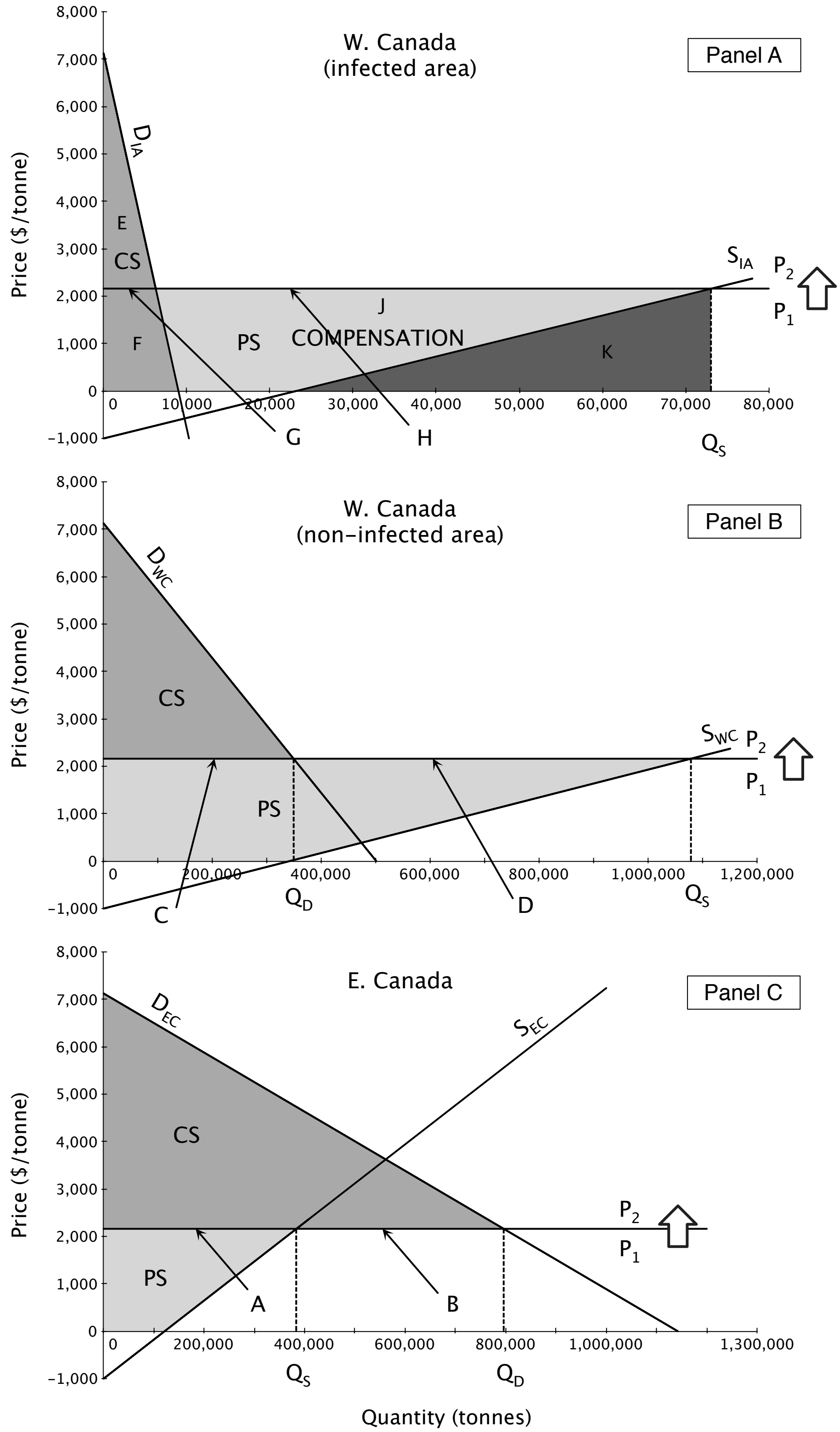


Figure 5.6: Scenario 3b: Small Outbreak - Compensation in Infected Area

Panels B and C are identical to the original panels from Scenario 3a. *Panel A* is where the change is found. Price increases to the new price P_2 which causes an increase in PS by amount $G + H$. Despite compensation being paid to producers, prices still collapse which causes CS to increase from E to $E + F$. The rectangular area labelled 'COMPENSATION' is shown shaded in dark-grey and partially obscured by the PS region. The compensation amount is the area of the rectangle from 0 to Q_S at a height of price P_2. In terms of the diagram it is the sum of areas $F + J + K$. This is the difference in the amount of animals supplied which are paid for through the compensation amount calculated as \$157,976,629.

Table 5.6 shows the totals when the change in CS, PS and TS are added up for all regions. Without compensation ΔTS was -\$86,095,350 and with compensation it is positive at \$17,903,294. Once more the amount of compensation for producers must be taken into account. The amount spent on compensation for producers is -\$157,976,629. Adding this value to ΔTS we get a new total of -\$140,073,334 which is nearly 62% higher than the non-compensated value.

Comparing the total costs in scenario 3b-with compensation to that of the No Trade scenario (scenario 1, -\$101,451,941) shows that a regionalization policy enforced through compensation is still less optimal than allowing trade to cease until the disease is brought under control. Of course, in this scenario the market totally collapses, with prices falling to zero. In reality other policies would likely be implemented to mitigate the effects of an FMD outbreak such that prices would not fall to zero. Consideration of those policies is beyond the scope of this thesis.

REGION	ΔCS(\$)	ΔPS(\$)	ΔTS(\$)
W.CAN.(IAC)	\$16,480,270	\$267,270	\$16,747,540
W.CAN.(NIA)	-\$1,276,375	\$3,941,579	\$2,665,204
E.CAN.	-\$2,911,559	\$1,402,108	-\$1,509,450
TOTAL	**\$12,292,337**	**\$5,610,958**	**\$17,903,294**
		COMPENSATION	**-\$157,976,629**
		TOTAL	**-\$140,073,334**

Table 5.6: Scenario 3b: Small Outbreak - Compensation in Infected Area

5.3 Conclusions

Conclusions are based on the assumption that the Base Case, in which there is full trade between Canada and the US, is the welfare maximizing situation. During an FMD outbreak surplus will change for consumers and producers and the goal will be to minimize the effects on TS. Table 5.7 summarizes the dollar change in surplus values for all the scenarios, including the scenarios where compensation is used. The scenarios are ranked by ΔTS in descending order to rank them from best to worst. In terms of TS for Canada all scenarios report negative values. Unsurprisingly, having an FMD outbreak that leads to trade restrictions makes Canadians worse off. Each scenario will be discussed in their ranking from best to worst outcome.

SCEN.	REGION	ΔCS($)	ΔPS($)	ΔTS($)
3b	W.CAN.(IA)	$16,480,270	-$103,731,374	-$87,251,104
	W.CAN.(NIA)	-$1,276,375	$3,941,579	$2,665,204
	E.CAN.	-$2,911,559	$1,402,108	-$1,509,450
	TOTAL	**$12,292,337**	**-$98,387,686**	**-$86,095,350**
1	W.CAN.	$199,135,482	-$560,194,297	-$361,058,815
	E.CAN.	$446,226,335	-$186,619,461	$259,606,873**
	TOTAL	**$645,361,817**	**-$746,813,758**	**-$101,451,941**
3b	W.CAN.(IAC)	$16,480,270	$267,270	$16,747,540
	W.CAN.(NIA)	-$1,276,375	$3,941,579	$2,665,204
	E.CAN.	-$2,911,559	$1,402,108	-$1,509,450
	TOTAL	**$12,292,337**	**$5,610,958**	**$17,903,294**
			COMPENSATION	**-$157,976,629**
			TOTAL	**-$140,073,334**
3a	W.CAN.(IA)	$151,721,755	-$638,105,118	-$486,383,363
	W.CAN.(NIA)	-$6,733,610	$15,951,274	$9,217,665
	E.CAN.	-$18,019,449	$8,720,372	-$9,299,076
	TOTAL	**$126,968,697**	**-$613,433,471**	**-$486,464,774**
2	W.CAN.	$767,183,948**	-$1,491,963,354*	-$724,779,406*
	E.CAN.	-$63,805,780*	$31,344,974**	-$32,460,806
	TOTAL	**$703,378,168**	**-$1,460,618,380**	**-$757,240,212**
3a	W.CAN.(IAC)	$151,721,755	$10,225,538	$161,947,293
	W.CAN.(NIA)	-$6,733,610	$15,951,274	$9,217,665
	E.CAN.	-$18,019,449	$8,720,372	-$9,299,076
	TOTAL	**$126,968,697**	**$34,897,185**	**$161,865,882**
			COMPENSATION	**-$986,249,452**
			TOTAL	**-$824,383,570**

Table 5.7: All Scenarios: Change in Surplus ($) Ranked by ΔTS
(* = lowest value **=highest value)

5.3.1 Scenario 3b - Small Outbreak with No Compensation

The small outbreak caused major disruption in the infected area due to the collapse in prices. CS increased a great deal due to the lower prices that consumers paid. The collapse in prices meant that producers were getting far less for their product which leads to a large decrease in PS. Producers were not compensated at prices the rest of Canada received. Overall the ΔTS for all of Canada was -$86,095,350, which was the best (least worst) outcome. This scenario is, however, likely unsustainable due to the large incentive to smuggle that remains. Compensation is a critical mechanism to ensure that animals are not smuggled to regions with higher prices. Also, sophisticated and fully enforced animal traceability systems (including animal movement tracking, premises identification and animal ID) would be required in order to facilitate the establishment of disease free zones. While Canada currently has a mandatory cattle ID system, it is unlikely that in its present state it would be sufficient to enforce disease free regions with this level of precision. The costs of implementing and enforcing these systems would be in addition to the costs measured here.

The sustainable situation in which compensation is used is discussed in the section "Scenario 3b - Small Outbreak with Compensation" below.

5.3.2 Scenario 1 - No Trade

In this scenario, trade to the US is cut off for the whole country during the outbreak. Canada moves to a new equilibrium price which is lower than the price under trade. As a result CS increases because consumers are paying less and PS decreases because producers are receiving a lower price than under full trade. Since there is no price difference in the country there is no incentive for producers to smuggle animals within Canada and therefore no compensation is required. ΔTS for all of Canada was -\$101,451,941 which makes this the second best outcome. Since the previous scenario has been deemed unsustainable due to the threat of disease spread, it could be argued that this is the least cost outcome.

This result seems counterintuitive. It was expected that allowing partial trade through regionalization would be a benefit to Canada over having no trade. The explanation as to why this scenario provides relatively good results is twofold. First, there is only a small increase in price when trade is suspended. When trade is suspended, prices decrease in Canada from the extra supply that was to be exported to the US.[2] The decrease in price causes CS to increase as consumers benefit from lower prices, whereas producers are made worse off from the lower price causing PS to decrease. Since the change in price is small, the change in CS and PS is not drastic and the changes in surplus are not drastically different in magnitude for consumers or producers. In the other scenarios where prices decrease dramatically, the positive benefits to consumers (ΔCS) are largely overwhelmed by the negative benefits to producers (ΔPS). The second reason for this

[2] The reason for this is that supply increases and demand remains constant. Since there is now an excess of supply, prices must decrease in order for the market to clear.

outcome is that trade still continues from west to east, despite trade being closed to the US. Compare this result to scenario 2 in which trade from western Canada is halted.

It is expected that in the case of an outbreak of FMD in a minor beef producing region, a regionalization policy could still yield lower economic losses than the no trade case considered here, and this is a topic for further research.

5.3.3 Scenario 3b - Small Outbreak with Compensation

This is the small outbreak scenario in which producers in the infected areas are compensated at the prices producers in the rest of Canada receive. As a result the changes in CS and PS are both positive and less severe than without compensation. The risk of disease spread is virtually eliminated because producers have no incentive to smuggle animals since all producers are getting the same price. Therefore this scenario is more likely to be sustainable than the scenario where compensation is not used. The true cost, however, must include the compensation that is paid to producers. Since the changes in surplus for the uninfected areas are exactly the same as they are for the scenario without compensation, the compensation paid only affects the infected area. The amount of compensation for this scenario was calculated at \$157,976,629. Since compensation is paid from government revenue in the form of taxes, the value is subtracted from ΔTS which results in a value of -\$140,073,334.

Comparing this scenario's ΔTS outcome (-\$140,073,334) to scenario 1's outcome (-\$101,451,941), scenario 1 still appears to be more desirable. In other words, a full trade suspension with the US during a small FMD outbreak in a beef surplus area is better than having a regionalization policy with partial trade. But when you look at the winners and losers in these scenarios the story changes in terms of distributional effects. In scenario 1, ΔCS is a very large positive number and ΔPS is very large negative number. CS is high due to the decrease in price which harms producers in terms of PS. Consumers are winners and producers are losers. Inspecting these surplus changes in the current scenario with compensation, producers are made better off as well as consumers. Both consumers and producers are winners in this scenario at the expense of the costs of compensation borne by taxpayers. Furthermore, the complete collapse of the market in the infected region would likely necessitate other policies to ameliorate the effect.

5.3.4 Scenario 3a - Large Outbreak with No Compensation

This is the large outbreak scenario in which no compensation is paid to producers. As the larger outbreak occurs in a more densely populated cattle region, the effects are larger in magnitude compared to the small outbreak. Once more the infected area is affected by the collapse in prices, with consumers benefiting and producers worse off. Overall ΔTS is -\$486,464,774 which is more than twice the magnitude of the previous outcome. This scenario, however, is likely unsustainable because there is a large incentive to smuggle.

If we think of this scenario as an escalation of disease spread from a small outbreak to a large outbreak (scenario 3b to 3a), it would have been advisable to contain the outbreak before it became large, assuming the disease was detected at the early stages. By compensating producers when the outbreak was small, the outcome would be much better than what we have here. If compensation were to be introduced now, the outcome would be far worse because of the number of animals that producers would need to be compensated for. This is shown by the results of scenario 3a with compensation. The better option would be to move to the situation found in scenario 1 in which trade is suspended completely.

Again, the complete collapse of this market leads to prices falling to zero. In reality, other policies would be needed to ameliorate the impacts, to ensure that beef is still available to consumers in this region and to deal with the surplus of cattle that would result.

5.3.5 Scenario 2 - Trade with Eastern Canada Only

This is the scenario where an outbreak occurs in western Canada and international trade is only allowed from eastern Canada. Animal movements from west to east are prevented at the West Hawk Lake Zoning Initiative. Complete animal movement tracking is not required because all animal movements from western to eastern Canada can be prevented. Prices in eastern Canada rise to the new US price which is higher because of the ceasing of imports from western Canada. With higher prices in eastern Canada CS decreases and PS increases. In western Canada the opposite situation occurs as prices decrease to clear the market of excess supply that can no longer be exported to eastern Canada and the US. The overall change in $TS$is -\$757,240,212 which is approximately 55% higher in magnitude than the previous outcome. Compared to scenario 1, in which there is no trade for the entire country, the magnitude is more than 7 times greater.

The reason for this is that in scenario 1, exports from western Canada can still go to eastern Canada. In this scenario, no animals are exported from western Canada.

Another way to look at this scenario is a contained FMD outbreak with no producer compensation. Because there is no compensation, producers can be expected to smuggle their animals to eastern Canada in search of higher prices. However animal movements are stopped at West Hawk Lake and compensation will not be needed. Even without the addition of compensation, the outcome of this scenario is the second worst of all the scenarios. In this case, moving to a situation like scenario 1 would be preferable because it would allow the movement of animals to eastern Canada providing a better outcome, as seen in the results.

It is therefore clear that a regionalization policy, even as broadly based an east/west divide at West Hawk Lake, is not necessarily a preferred response to a FMD outbreak relative to closing off all international trade until the disease is contained (if the disease outbreak is in the west).

5.3.6 Scenario 3a - Large Outbreak with Compensation

The worst case scenario that was examined is the large outbreak with compensation. Compensation is very large because the size of the infected area is large and producers need to be compensated for every single animal. The same scenario without compensation would have a better outcome in terms of ΔTS but as has been discussed, a scenario without compensation would not be sustainable and would lead to smuggling and disease spread.

Scenario 2, which has no compensation, would be preferable in terms of ΔTS. Since animal movements would be stopped at West Hawk Lake, compensation would not required. Producers wanting to smuggle their animals to eastern Canada in search of higher prices would be unsuccessful. The problem with this scenario, as was discussed previously, is that preventing exports from western Canada to eastern Canada results in high losses to PS. Moving to scenario 1 would allow western Canada exports to continue and provide a better outcome as seen in the results.

5.3.7 Summary of Conclusions

After analyzing the results, the following conclusions are offered:

1. Regionalization in western Canada would only be sustainable if compensation is given to producers in infected areas. Without compensation, there is an incentive for producers to smuggle their animals to regions with higher prices. Since FMD is such a contagious disease, the risk of disease spread is very high.

2. A non-regionalization policy, in which trade is suspended for the whole country, provides a better outcome in terms of TS compared to scenarios involving regionalization when disease outbreak occurs in beef surplus regions. However, producers suffer greatly at the expense of gains to consumers.

3. If an FMD outbreak is small in size and compensation is used (along with other disease containment policies), the outbreak will most likely be contained. Although compensation will decrease TS, changes to CS and PS will be positive.

4. The only way regionalization could be achieved without compensation would be if animal movements could be monitored such that smuggling could not occur. In Canada, this could only be achieved through monitoring at West Hawk Lake due to the geographical characteristics of the region (see scenario 2). In the case of a disease outbreak in the west, however, the loss in PS would be extremely high and lead to a very large decrease in TS because trade to eastern Canada is not allowed.

5. If the FMD outbreak is large, costs will be very high when compensation is taken into account. Money spent on monitoring and controlling FMD outbreaks is a wise investment compared to the cost incurred from a large outbreak.

6. In terms of TS, the results show that regionalization is not necessarily a preferable policy to complete trade shutdown. The results show that in a non-regionalization scenario, when the disease outbreak is in a major beef producing area, consumers are better off and producers are worse off. In a regionalization scenario where compensation is used, both consumers and producers are better off. If the outbreak is small in size, the outcome is slightly worse than if trade is shut down until the disease is contained.

5.4 Suggested Policy Responses

It is assumed that Canada will be best off under the Base Case scenario when there is no livestock disease outbreak and is trading fully with the US at a consistent price. The results from the analysis show that any FMD outbreak will decrease surplus and make the country worse off. Therefore policies that ensure Canada stays disease-free are needed. In the event of a disease outbreak policies are needed to minimize the spread and duration of disease in order to return to the Base Case scenario as soon as possible.

The last FMD outbreak in Canada was in 1952 and in the US the last outbreak was in 1929. FMD outbreaks have occurred in other countries in recent years causing very large losses so Canada and the US should remain vigilant and ensure that FMD outbreaks do not occur.

If an FMD outbreak were to occur in Canada then having a full traceability system would enable the identification of animals that could have been exposed to the disease. By vaccinating or destroying susceptible animals the spread of disease can be contained and eradicated. Without a full traceability system it will be difficult to identify animals that could have been exposed and large culls may be required to ensure that all potentially exposed animals are destroyed, including animals that were not exposed. A full traceability systems includes animal registration, premises registration and complete animal movement information. Carlberg (2010) reports that animal movement tracking is not yet implemented for all of Canada and may not be for some time due to the amount of work it will require of producers and the expense of setting up the system (Carlberg, 2010). At the time of this writing, premise ID and animal movement tracking are optional. Age verification is also optional, except in Alberta where it is mandatory. Refer to section 1.2.2 for more information on the status of traceability in Canada.

A cattle ID traceability system that is mandatory with 100% compliance from producers will be more effective at responding to an FMD outbreak. If some producers do not participate then there is no way to ensure that all animal movements have been recorded. In the event of an FMD outbreak all animal movements must be known. Any obstacles that prevent a producer from registering animal movements reduce the effectiveness of the system. Therefore a traceability system needs to be easy to use and not place any undue hardship on producers. Penalties for non-compliance need to be considered.

Compensation could be an effective policy instrument to eliminate the incentive to smuggle animals and cause the spread of disease. Unless the outbreak is small and in a minor beef producing region, compensation will be very costly and exceed the loss in surplus if compensation were not used. Compensation is a function of the number of animals in the infected area so it will be high if the size of the infected area is high, as seen in the results. Although compensation can be quite costly, it is a critical insurance mechanism to help prevent the spread of disease when there is a price differential between infected and non-infected regions.

In the scenarios developed in this thesis where compensation is paid, the very large values for compensation arise because the areas are very large net exporters, which causes the market to collapse and price to fall to zero for consumers. If areas that were smaller net exporters were chosen, compensation payments would be reduced.

5.5 Limitations and Suggestions for Future Research

This project has taken a very basic approach to modelling small and large FMD outbreaks in Alberta by estimating the number of animals culled in scenarios 3a and 3b. The analysis could be improved by simulating an FMD outbreak with an epidemiological model such as the "North American Animal Disease Spread Model" (NAADSM).[3] This would provide more accurate information about the number of animals culled, duration of the outbreak and associated costs to eliminate the outbreak. For further information regarding the use of NAADSM, refer to appendix C.

The costs that were used to quantify the outbreak included only the price of a typical animal. Other costs associated with an outbreak including monitoring animal movements (e.g. West Hawk Lake), setting up quarantine zones, culling animals and the cleaning/disinfection of premises were not included. Therefore the true costs of the outbreak were underreported.

The beef sector was the only sector examined in the analysis. Other sectors would also likely be affected by an FMD outbreak (e.g. the hog sector, dairy cattle). The simplifying assumptions were made to focus on the trade effects of regionalization under different scenarios. It is the relative size of these outcomes that provide the focus of the research. They should not be taken to represent the full cost of a FMD outbreak.

[3]North American Animal Disease Spread Model. Internet Site: http://www.naadsm.org

Furthermore, in the smaller regional scenarios, price fell to zero because the markets for beef completely collapsed. In reality other policies would be needed to prevent these markets from completely collapsing. Since the focus of this thesis was on the question of regionalization, consideration of these policies was beyond the scope of the present analysis, but would be a useful topic for further research.

A simplifying assumption was made that the regions where FMD outbreaks occurred would have access to slaughter plants. However, it would not be safe to transport infected animals outside of their quarantine zones. The actual location of slaughter plants in Alberta and elsewhere should be factored in to future analysis that uses the methodology in this thesis.

Losses were only analyzed at the producer level of the supply chain. Losses in other parts of the supply chain could also be examined such as packers, auction markets, and the livestock transportation sector.

The scenarios is this project focussed on FMD outbreaks in western Canada only. The same methodology could be extended to outbreaks in eastern Canada to compare and contrast with the results found here. The resulting changes in surplus would be different since eastern Canada is an importer of beef and livestock from western Canada and the US.

5.6 Contribution

This thesis has contributed to the body of research on regionalization by quantifying the costs of an FMD outbreak involving various degrees of regionalization. The results will help guide future research into this topic using it as a basis for further study in Canada or applying the framework to other countries.

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Appendix A

Appendix A - Initial Data Set Calculations

This appendix details the sources of the initial datasets and the calculations that were performed for Canada and the US to derive supply and demand. Animal numbers are all in tonnes (meat equivalents) and all data is for the year 2010 except where noted.

A.1 Canada Dataset

Table A.1 summarizes the Canadian data by region. The following sections detail the calculations and sources for each row (a) to (i).

	CANADA, 2010	W. CANADA	E. CANADA	CANADA TOTAL
(a)	Total Cattle Slaughter: Prov & Fed Plants (tonnes)	960,751.1	346,871.4	1,307,622.5
(b)	Total Steer-Heifer Exports to US (tonnes)	189,614.0	36,353.7	225,967.7
(c)	Beef and Veal Exports Canada to US (tonnes)	220,390.1	88,396.9	308,787.0
(d)	TOTAL Exports (tonnes)	410,004.1	124,750.6	534,754.7
(e)	Beef and Veal Imports US to Canada (tonnes)	0.0	153,177.0	153,177.0
(f)	Population, 2010	10,514,509	23,561,099	34,075,608
(g)	SUPPLY (Q_1, tonnes)	1,150,365.1	383,225.1	1,533,590.2
(h)	DEMAND (tonnes)	740,361.0	411,651.5	1,152,012.5
(i)	WEIGHTED DEMAND (Q_1, tonnes)	355,469.7	796,542.8	1,152,012.5

Table A.1: Canada Supply and Demand

A.1.1 (a) Total Cattle Slaughter: Provincial & Federal Plants (tonnes)

Table A.2 shows the data used to convert slaughter cattle head to tonnes of meat equivalent. Row (a) shows the number of head of slaughter cattle processed in federally inspected plants per region of Canada. Row (b) shows the number of head of slaughter cattle processed in provincially inspected plants in the same regions. Row (c) is the sum of rows (a) and (b) and is the total number of head. Row (d) is the average carcass weight in pounds of steer for plants in the region. Multiplying rows (c) and (d) gives us the pounds of beef equivalent shown in row (e). This number is converted to tonnes by dividing the number in row (e) by 2,206.62 which gives us the total cattle slaughter in tonnes of beef equivalent (1 tonne = 2,204.62 pounds).

	CATEGORY	W. CANADA BC, SK, MB	AB	E. CANADA ON	QB-ATL CA	TOTAL
(a)	Cattle Slaughter (head) Fed. Insp. Plants (2010) (1)	6,058	2,439,796	577,819	186,632	3,210,305
(b)	Cattle Slaughter (head) Prov. Insp. Plants (2010) (2)	38,802	31,145	88,046	33,527	191,520
(c)	**TOTAL Slaughter (head)**	**44,860**	**2,470,941**	**665,865**	**220,159**	**3,401,825**
(d)	Average Cattle Carcass Weights (Steers, 2010) for Federal Slaughter (lbs.) (3)	672	845	878	818	853
(e)	Lbs of Beef Equivalent	30,145,920.0	2,087,945,145.0	584,629,470.0	180,090,062.0	2,882,810,597.0
(f)	**Total Cattle Slaughter (tonnes of Beef Equivalent)**	**13,674.0**	**947,077.1**	**265,183.8**	**81,687.6**	**1,307,622.4**

Table A.2: Slaughter Cattle in tonnes of beef equivalent

Source: (1) (Agriculture and Agri-Food Canada, 2012b) (2) (Agriculture and Agri-Food Canada, 2012e) (3) (Agriculture and Agri-Food Canada, 2012a)

Table A.3 shows the quantities in row (e) totalled up per region. These are the quantities found in Table A.1, row (a).

PROV	TOTAL CATTLE SLAUGHTER (TONNES)
BC, SK, MB	13,674.0
AB	947,077.1
W. CANADA TOTAL	**960,751.1**
ON	265,183.8
QB-ATL	81,687.6
E. CANADA TOTAL	**346,871.4**
CANADA TOTAL	**1,307,622.5**

Table A.3: Total Slaughter Cattle in tonnes of beef equivalent per region

A.1.2 (b) Total Steer-Heifer Exports to US (tonnes)

This data for this category could not be found directly so a methodology was developed to estimate the quantities. This was done by finding the total number head exported to the US through all ports of entry and distributing it to the specific regions. This was accomplished by dividing the total number of animals per state crossing by the grand total resulting in a percentage of the total. These state percentages were added up to create provincial percentages. Table A.4 shows the number of animal crossings by state and the conversion of the total to a percentage.

US STATE	STEERS/HEIFERS	% OF TOTAL
Idaho	261,446	
Montana	155,340	
TOTAL AB	**416,786**	**68.1**
Washington	8,810	
North Dakota	89,170	
TOTAL REST OF W. CANADA	**97,980**	**16.0**
Minnesota	0	
Illinois	0	
Michigan	10,706	
TOTAL ON	**10,706**	**1.7**
Pennsylvania	0	
Georgia	0	
New York	80,556	
Vermont	5,366	
Maine	565	
TOTAL QB-ATL CA	**86,487**	**14.1**
TOTAL CANADA	**611,959**	**100.0**

Table A.4: Steers/Heifers Crossing through US Ports of Entry

Source: (Agriculture and Agri-Food Canada, 2012f)

Table A.5 shows the percentages aggregated up to Canadian provinces. Table A.6 shows the percentages aggregated up to Canadian regions which are the entries found in Table A.1, row (b).

		W. CANADA		E. CANADA		CANADA TOTAL
	CATEGORY	BC, SK, MB	AB	ON	QB-ATL CA	
(a)	Steers-Heifers exported to US through ports of entry (% of Total)	16.0	68.1	1.7	14.1	100.0
(b)	Total Steers-Heifers Exports to the US	97,980	416,786	10,706	86,487	611,959
(c)	Average Cattle Carcass Weights for Federal Slaughter (lbs.) (1)	672	845	878	818	853
(d)	Lbs of Beef Equivalent	65,842,560	352,184,170	9,399,868	70,746,366	498,172,964.0
(e)	**Total Steer-Heifer Exports to US (tonnes of Beef Equivalent)**	**29,865.7**	**159,748.2**	**4,263.7**	**32,090.0**	**225,967.7**

Table A.5: Total Steer-Heifer Exports to US by Province

Source: (1) (Agriculture and Agri-Food Canada, 2012a)

	Total Steer-Heifer Exports to US (tonnes)
BC, SK, MB	29,865.7
AB	159,748.2
TOTAL W. CANADA	**189,614.0**
ON	4,263.7
QB, ATL-CA	32,090.0
TOTAL E. CANADA	**36,353.8**
TOTAL CANADA	**225,967.7**

Table A.6: Total Steer-Heifer Exports to US by Region

A.1.3 (c) Beef and Veal Exports - Canada to US (tonnes)

This data was not found directly so a methodology was developed to estimate the quantities. This was done by finding the amount of bovine product exported by province in dollars to determine a percentage exported by province. Table A.7 shows the categories that were used to run a report on the Government of Canada - Industry Canada website (Industry Canada, 2013). The report was run for each province to get the total exports by year. These numbers were then converted to percentages to show the percentage amount exported by province (Table A.8). These percentages were then multiplied by the total Beef and Veal exports from Canada to the US to find the amount exported by province. Canada exported 308,787 tonnes of Beef and veal products to the US in 2010 (Agriculture and Agri-Food Canada, 2012c). The provincial numbers were then aggregated to the regional levels (Table A.9) which are found in Table A.1, row (c).

HS 020110 - BOVINE, CARCASSES AND HALF-CARCASSES - FRESH OR CHILLED
HS 020120 - BOVINE, CUTS WITH BONE IN - FRESH OR CHILLED
HS 020130 - BOVINE, CUTS BONELESS - FRESH OR CHILLED
HS 020210 - BOVINE, CARCASSES AND HALF-CARCASSES - FROZEN
HS 020220 - BOVINE, CUTS WITH BONE IN - FROZEN
HS 020230 - BOVINE, CUTS BONELESS - FROZEN

Table A.7: Bovine categories included in Industry Canada report

A.1.4 (d) Total Exports (tonnes)

This row is the total amount of meat equivalent product exported from Canada to the US by region in the form of slaughter cattle or processed meat products. It is simply the sum of row (b) and (c).

A.1.5 (e) Beef and Veal Imports - US to Canada (tonnes)

This row shows the tonnes of beef and veal products that are exported to Canada from the US. The US exported 153,177.0 tonnes of beef and veal products (Agriculture and Agri-Food Canada, 2012c). The assumption being made is that all of the US exports go to eastern Canada only. The amounts are found in Table A.1, row (e).

	2010	% BY PROV
Alberta	694,097,620	70.9
Ontario	211,982,060	21.7
Quebec	68,153,299	7.0
British Columbia	3,255,892	0.3
Saskatchewan	1,076,965	0.1
Prince Edward Island	0	0.0
Manitoba	0	0.0
New Brunswick	0	0.0
Nunavut	0	0.0
Northwest Territories	0	0.0
Nova Scotia	0	0.0
Yukon Territory	0	0.0
Newfoundland and Labrador	0	0.0
TOTAL	978,567,846	100.0

Table A.8: Trade Data Online Report - Total Exports of Bovine Products
Source: (Industry Canada, 2013)

BLANK	CDN $ % by Prov 2010	tonnes/Prov	W. Canada	E. Canada
Alberta	70.9	219,022.9	219,022.9	
Ontario	21.7	66,891.1		66,891.1
Quebec	7.0	21,505.8		21,505.8
British Columbia	0.3	1,027.4	1,027.4	
Saskatchewan	0.1	339.8	339.8	
TOTAL	**100.0**	**308,787.0**	**220,390.1**	**88,396.9**

Table A.9: Beef and Veal Exports - Canada to US (tonnes)

A.1.6 (f) Population, 2010

This row contains the regional populations in Canada in 2010 (Statistics Canada, 2012). Population will be used to calculate the weighted demand figure detailed below. The individual provinces are totalled up to the regional levels found in Table A.1, row (f).

A.1.7 (g) Supply (Q_1, tonnes)

Supply is calculated by summing rows (a) and (b). This total gives the total supply of meat equivalent products in tonnes for each region. Supply is found in Table A.1, row (g).

A.1.8 (h) Demand (tonnes)

Demand is calculated by subtracting beef and veal exports (c) from the total cattle slaughter (a) and then adding imports from the US (e). In terms of Table A.1, demand is calculated as $(a) - (c) + (e)$. These results are found in Table A.1, row (h).

A.1.9 (i) Weighted Demand (Q_1, tonnes)

The demand number that is used in all calculations is a weighted demand based on population figures found in row (f). Percent population is found by dividing the population of the region by the total population. This percentage is multiplied by the total demand for Canada to give the weighted demand for the region. Table A.10 shows the calculations that are found in Table A.1, row (i).

	W. CANADA	REST OF CANADA	TOTAL
Population, 2010	10,514,509	23,561,099	34,075,608
% Population, 2010	30.9	69.1	100.0
DEMAND (tonnes)	740,361.0	411,651.5	1,152,012.5
Weighted Demand (Q_1, tonnes)	**355,469.7**	**796,542.8**	**1,152,012.5**

Table A.10: Weighted Demand (Q_1, tonnes)

A.2 US Dataset

Table A.11 summarizes the US data used to derive supply and demand. The following sections detail the calculations and sources for each row (a) to (l).

ROW	CATEGORY	NUMBERS
(a)	US Total Cattle Slaughter: Fed and Other Plants (# head)	34,265,200.0
(b)	US Average Dressed Weight - Cattle (lbs)	773.0
(c)	Lbs of Beef Equivalent	26,486,999,600.0
(d)	Total Cattle Slaughter (tonnes of Beef Equivalent)	12,014,315.2
(e)	Total Steer-Heifer Imports from Canada (tonnes)	225,967.7
(f)	Beef and Veal Exports US to World (tonnes)	1,067,279.0
(g)	Supply of Beef produced in US (tonnes)	10,721,068.5
(h)	Total Canada Exports to US (tonnes)	534,754.7
(i)	Beef and Veal Imports US to Canada (tonnes)	153,177.0
(j)	Canada Net exports to US	381,577.7
(k)	US Consumption (tonnes)	11,102,646.2
(l)	**SUPPLY (Q_1, tonnes)**	**11,102,646.2**
(m)	**DEMAND (Q_1, tonnes)**	**11,102,646.2**

Table A.11: US Supply and Demand

A.2.1 (a) US Total Cattle Slaughter: Fed and Other Plants

This number is the total number head of cattle slaughtered in the US in federally inspected plants and all other plants in 2010 (US Dept of Agriculture, 2010).

A.2.2 (b) US Average Dressed Weight - Cattle (lbs)

This number is the average dressed weight of cattle in federally inspected plants in 2010 (US Dept of Agriculture, 2010).

A.2.3 (c) Lbs of Beef Equivalent

This number is the lbs of beef equivalent found by multiplying the number of head by the average dressed weight: $(c) = (a) * (b)$.

A.2.4 (d) Total Cattle Slaughter (tonnes of Beef Equivalent)

This number is the quantity in (c) converted to tonnes which is calculated by dividing (c) by 2,204.62 (1 tonne = 2,204.62 lbs).

A.2.5 (e) Total Steer-Heifer Imports from Canada (tonnes)

This is the total Canadian quantity of steer-heifer exports from Canada to the US (2010) shown in Table A.1, row (b).

A.2.6 (f) Beef and Veal Exports US to World (tonnes)

This is the total beef and veal exports (tonnes) the US exported to the world in 2010 (Agriculture and Agri-Food Canada, 2012c).

A.2.7 (g) Supply of Beef produced in US (tonnes)

This is the US supply of beef in 2010. It is calculated as follows: $(d) - (e) - (f)$

A.2.8 (h) Total Canada Exports to US (tonnes)

This is the total exports from Canada to the US (tonnes) in 2010. It is taken from Table A.1, row (d).

A.2.9 (i) Beef and Veal Imports US to Canada (tonnes)

This is the total beef and veal imports (tonnes) the US exported to Canada in 2010 (Agriculture and Agri-Food Canada, 2012c).

A.2.10 (j) Canada Net exports to US (tonnes)

This is the net exports from Canada to the US in 2010. It is calculated as follows: $(h) - (i)$

A.2.11 (k) US Consumption (tonnes)

This is the total US consumption of meat (tonnes). It is the sum of US supply plus the amount imported from Canada and is calculated as follows: $(g) - (j)$ This becomes the quantity of both supply and demand in the US shown in rows (l) and (m).

A.2.12 (l) Supply (Q_1, tonnes)

This quantity is the same as US Consumption described in row (k).

A.2.13 (m) Demand (Q_1, tonnes)

This quantity is the same as US Consumption described in row (k).

A.3 US Price P_1

The data used to arrive at the US price are shown in Table A.12. This gives the *ROW* price of $2,156.41 that is used in many of the examined scenarios. The following sections detail the data sources and calculations that were performed.

	CATEGORY	VALUE
(a)	Sales and Weighted Average Prices per 100 lbs (Steers, US$)	94.97
(b)	US $ Price in CDN$ per 100 lbs.	97.81
(c)	Price per lb.	0.9781
(d)	Price per tonne	2,156.41

Table A.12: US Price Calculations

A.3.1 (a) Sales and Weighted Average Prices per 100 lbs (Steers, US$)

This number is the average US$ price per 100 lbs of steers in the US. It was found in Agriculture and Agri-Food table A025 by selecting 'steers' and 2010 and generating a report (Agriculture and Agri-Food Canada, 2012d). The category the number was chosen from is 'DIRECT TO PACKERS (U.S. 5 AREA) CHOICE STEERS 65-80% Choice' which is $94.97 (US).

A.3.2 (b) US $ Price in CDN$ per 100 lbs.

This is the number from row (a) converted to Canadian dollars based on the exchange rate on Jan 1 2011 which was 1.02993904 (Bank of Canada, 2013). This number is multiplied by the US price in (a) to give the price in Canadian dollars of $97.81.

A.3.3 (c) Price per lb.

This is the price in row (b) which is the price per 100 lbs converted to lbs. This is calculated by dividing (b) by 100.

A.3.4 (d) Price per tonne

This is the number in row (c) which is price in lbs converted to tonnes. This gives the price per tonne and is calculated by multiplying (c) by 2,204.62 (1 tonne = 2,204.62 lbs). This gives the number 2,156.41 which is the US price per tonne of beef in Canadian dollars. This number is used as P_1 in the scenarios examined.

Appendix B

Appendix B - Data Tables

This appendix shows the numbers calculated in each scenario. The table at the top of the page contains the values used to calculate Q_1 for both supply and demand using the methodology discussed in chapter 4. The tables at the bottom of each page show the calculated numbers for P_2 and Q_2 for both supply and demand. This forms the basis for the supply and demand curves from which the welfare analysis is derived for each scenario and compared with the base case welfare measures.

B.1 Base Case

CANADA, 2010	W. CANADA	E. CANADA	CANADA TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	960,751.1	346,871.4	1,307,622.5
Total Steer-Heifer Exports to US (Tonnes)	189,614.0	36,353.7	225,967.7
Beef and Veal Exports Canada to US (Tonnes)	220,390.1	88,396.9	308,787.0
Total Exports (tonnes)	410,004.1	124,750.6	534,754.7
Beef and Veal Imports US to Canada (Tonnes)	0.0	153,177.0	153,177.0
Population, 2010	10,514,509	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	1,150,365.1	383,225.1	1,533,590.2
Demand (Tonnes)	740,361.0	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	355,469.7	796,542.8	1,152,012.5

Table B.1: Base Case

DEMAND	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	355,469.7	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
ΔQ	-15,427.4	-34,570.0	-49,997.3	-466,200.1
Q_2	340,042.3	761,972.9	1,102,015.2	10,636,446.1
m	-1.397781 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,291.94
SUPPLY	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	1,150,365.1	768,116.4	1,533,590.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
ΔQ	78,569.9	52,462.4	104,744.2	1,010,340.8
Q_2	1,228,935.0	820,578.8	1,638,334.4	12,112,987.0
m	2.744574 $\times 10^{-3}$	4.110395 $\times 10^{-3}$	2.058739 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	485,932.5	785,251.6	1,275,301.1	11,102,646.2
P_e	332.83	2,226.84	1,624.66	2,156.41

Table B.2: Base Case - Supply/Demand

B.2 Scenario 1

CANADA, 2010	W. CANADA	E. CANADA	CANADA TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	960,751.1	346,871.4	1,307,622.5
Total Steer-Heifer Exports to US (Tonnes)	189,614.0	36,353.7	225,967.7
Beef and Veal Exports Canada to US (Tonnes)	220,390.1	88,396.9	308,787.0
TOTAL Exports (tonnes)	410,004.1	124,750.6	534,754.7
Beef and Veal Imports US to Canada (Tonnes)	0.0	153,177.0	153,177.0
Population, 2010	10,514,509	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	1,150,365.1	383,225.1	1,533,590.2
DEMAND (Tonnes)	740,361.0	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	355,469.7	796,542.8	1,152,012.5

Table B.3: Scenario 1

DEMAND	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	355,469.7	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
ΔQ	-15,427.4	-34,570.0	-49,997.3	-466,200.1
Q_2	340,042.3	761,972.9	1,102,015.2	10,636,446.1
m	-1.397781 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,291.94
SUPPLY	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	1,150,365.1	383,225.1	1,533,590.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
ΔQ	78,569.9	26,174.3	104,744.2	1,010,340.8
Q_2	1,228,935.0	409,399.4	1,638,334.4	12,112,987.0
m	2.744574 $\times 10^{-3}$	8.238662 $\times 10^{-3}$	2.058739 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	485,932.5	561,320.9	1,275,301.1	11,102,646.2
P_e	332.83	3,623.68	1,624.66	2,156.41

Table B.4: Scenario 1 - Supply/Demand

B.3 Scenario 2

CANADA, 2010	W. CANADA	E. CANADA	CANADA TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	960,751.1	346,871.4	1,307,622.5
Total Steer-Heifer Exports to US (Tonnes)	189,614.0	36,353.7	225,967.7
Beef and Veal Exports Canada to US (Tonnes)	220,390.1	88,396.9	308,787.0
TOTAL Exports (tonnes)	410,004.1	124,750.6	534,754.7
Beef and Veal Imports US to Canada (Tonnes)	0.0	153,177.0	153,177.0
Population, 2010	10,514,509	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	1,150,365.1	383,225.1	1,533,590.2
DEMAND (Tonnes)	740,361.0	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	355,469.7	796,542.8	1,152,012.5

Table B.5: Scenario 2

DEMAND	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	355,469.7	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
ΔQ	-15,427.4	-34,570.0	-49,997.3	-466,200.1
Q_2	340,042.3	761,972.9	1,102,015.2	10,636,446.1
m	-1.397781 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,291.94

SUPPLY	W. CANADA	E. CANADA	CANADA TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	1,150,365.1	383,225.1	1,533,590.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64
ΔQ	78,569.9	26,174.3	104,744.2	1,010,340.8
Q_2	1,228,935.0	409,399.4	1,638,334.4	12,112,987.0
m	2.744574 $\times 10^{-3}$	8.238662 $\times 10^{-3}$	2.058739 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	485,932.5	561,320.9	1,275,301.1	11,102,646.2
P_e	332.83	3,623.68	1,624.66	2,156.41

Table B.6: Scenario 2 - Supply/Demand

B.4 Scenario 3a - Large Outbreak Base Case

CANADA, 2010	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	384,513.3	576,237.8	346,871.4	1,307,622.5
Total Steer-Heifer Exports to US (Tonnes)	64,857.8	124,756.2	36,353.7	225,967.7
Beef and Veal Exports Canada to US (Tonnes)	88,923.3	131,466.8	88,396.9	308,787.0
TOTAL Exports (tonnes)	153,781.1	256,223.0	124,750.6	534,754.7
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0	153,177.0
Population, 2010	1,710,064	8,804,445	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	449,371.1	700,994.0	383,225.1	1,533,590.2
DEMAND (Tonnes)	295,590.0	444,771.0	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	57,813.1	297,656.6	796,542.8	1,152,012.5

Table B.7: Scenario 3a - Large Outbreak Base Case

DEMAND	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	57,813.1	297,656.6	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	-2,509.1	-12,918.3	-34,570.0	-49,997.3	-466,200.1
Q_2	55,304.0	284,738.3	761,972.9	1,102,015.2	10,636,446.1
m	-8.594402 $\times 10^{-2}$	-1.669268 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,125.10	7,291.94
SUPPLY	**W. CAN. (I.A.)**	**W. CAN. (N.I.A.)**	**E. CAN.**	**CAN. TOTAL**	**US**
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	449,371.1	700,994.0	383,225.1	1,533,590.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	30,692.0	47,877.9	26,174.3	104,744.2	1,010,340.8
Q_2	480,063.1	748,871.9	409,399.4	1,638,334.4	12,112,987.0
m	7.025958 $\times 10^{-3}$	4.503979 $\times 10^{-3}$	8.238662 $\times 10^{-3}$	2.058739 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	87,404.0	383,359.9	561,320.9	1,275,301.1	11,102,646.2
P_e	-386.76	725.79	3,623.68	1,624.66	2,156.41

Table B.8: Scenario 3a - Large Outbreak Base Case Supply/Demand

B.5 Scenario 3a - Large Outbreak

CANADA, 2010	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	337,028.3	576,237.8	346,871.4	1,260,137.5
Total Steer-Heifer Exports to US (Tonnes)	0.0	124,756.2	36,353.7	161,109.9
Beef and Veal Exports Canada to US (Tonnes)	0.0	131,466.8	88,396.9	219,863.7
TOTAL Exports (tonnes)	0.0	256,223.0	124,750.6	380,973.6
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0	153,177.0
Population, 2010	1,710,064	8,804,445	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	337,028.3	700,994.0	383,225.1	1,421,247.4
DEMAND (Tonnes)	337,028.3	444,771.0	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	57,813.1	297,656.6	796,542.8	1,152,012.5

Table B.9: Scenario 3a - Large Outbreak

DEMAND	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	57,813.1	297,656.6	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	-2,509.1	-12,918.3	-34,570.0	-49,997.3	-466,200.1
Q_2	55,304.0	284,738.3	761,972.9	1,102,015.2	10,636,446.1
m	-8.594402 $\times 10^{-2}$	-1.669268 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,125.10	7,291.94

SUPPLY	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	337,028.3	700,994.0	383,225.1	1,421,247.4	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	23,019.0	47,877.9	26,174.3	97,071.2	1,010,340.8
Q_2	360,047.3	748,871.9	409,399.4	1,518,318.6	12,112,987.0
m	9.367943 $\times 10^{-3}$	4.503979 $\times 10^{-3}$	8.238662 $\times 10^{-3}$	2.221472 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	85,256.3	383,359.9	561,320.9	1,243,541.5	11,102,646.2
P_e	-202.18	725.79	3,623.68	1,761.64	2,156.41

Table B.10: Scenario 3a - Large Outbreak Supply/Demand

B.6 Scenario 3b - Small Outbreak Base Case

CANADA, 2010	W. CAN. (I.A.)	W. CAN. (N.I.A)	E. CAN.	CAN. TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	62,507.1	898,244.0	346,871.4	1,307,622.5
Total Steer-Heifer Exports to US (Tonnes)	10,543.4	179,070.6	36,353.7	225,967.7
Beef and Veal Exports Canada to US (Tonnes)	14,455.5	205,934.6	88,396.9	308,787.0
TOTAL Exports (tonnes)	24,998.9	385,005.2	124,750.6	534,754.7
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0	153,177.0
Population, 2010	185,750	10,328,759	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	73,050.5	1,077,314.6	383,225.1	1,533,590.2
DEMAND (Tonnes)	48,051.6	692,309.4	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	6,279.8	349,189.9	796,542.8	1,152,012.5

Table B.11: Scenario 3b - Small Outbreak Base Case

DEMAND	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	6,279.8	349,189.9	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	-272.5	-15,154.8	-34,570.0	-49,997.3	-466,200.1
Q_2	6,007.2	334,035.1	761,972.9	1,102,015.2	10,636,446.1
m	-7.912236 $\times 10^{-1}$	-1.422918 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,125.10	7,291.94

SUPPLY	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	73,050.5	1,077,314.6	383,225.1	1,533,590.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	4,989.3	73,580.6	26,174.3	104,744.2	1,010,340.8
Q_2	78,039.8	1,150,895.2	409,399.4	1,638,334.4	12,112,987.0
m	4.322028 $\times 10^{-2}$	2.930678 $\times 10^{-3}$	8.238662 $\times 10^{-3}$	2.058739 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	9,738.2	473,544.0	561,320.9	1,275,301.1	11,102,646.2
P_e	-579.97	386.95	3,623.68	1,624.66	2,156.41

Table B.12: Scenario 3b - Small Outbreak Base Case Supply/Demand

B.7 Scenario 3b - Small Outbreak

CANADA, 2010	W.CAN. (I.A.)	W. CAN. (N.I.A.)	E CAN.	CAN. TOTAL
Total Cattle Slaughter: Prov & Fed Plants (Tonnes)	65,745.4	898,244.0	346,871.4	1,310,860.8
Total Steer-Heifer Exports to US (Tonnes)	0.0	179,070.6	36,353.7	215,424.3
Beef and Veal Exports Canada to US (Tonnes)	0.0	205,934.6	88,396.9	294,331.5
TOTAL Exports (tonnes)	0.0	385,005.2	124,750.6	509,755.8
Beef and Veal Imports US to Canada (Tonnes)	0.0	0.0	153,177.0	153,177.0
Population, 2010	185,750	10,328,759	23,561,099	34,075,608
SUPPLY (Q_1, Tonnes)	65,745.4	1,077,314.6	383,225.1	1,526,285.2
DEMAND (Tonnes)	65,745.4	692,309.4	411,651.5	1,152,012.5
WEIGHTED DEMAND (Q_1, Tonnes)	6,279.8	349,189.9	796,542.8	1,152,012.5

Table B.13: Scenario 3b - Small Outbreak

DEMAND	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	6,279.8	349,189.9	796,542.8	1,152,012.5	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	-272.5	-15,154.8	-34,570.0	-49,997.3	-466,200.1
Q_2	6,007.2	334,035.1	761,972.9	1,102,015.2	10,636,446.1
m	-7.912236 $\times 10^{-1}$	-1.422918 $\times 10^{-2}$	-6.237815 $\times 10^{-3}$	-4.313049 $\times 10^{-3}$	-4.625503 $\times 10^{-4}$
b	7,125.10	7,125.10	7,125.10	7,125.10	7,291.94
SUPPLY	W. CAN. (I.A.)	W. CAN. (N.I.A.)	E. CAN.	CAN. TOTAL	US
P_1	2,156.41	2,156.41	2,156.41	2,156.41	2,156.41
Q_1	65,745.4	1,077,314.6	383,225.1	1,526,285.2	11,102,646.2
P_2	2,372.05	2,372.05	2,372.05	2,372.05	2,372.05
ΔP	215.64	215.64	215.64	215.64	215.64
ΔQ	4,490.4	73,580.6	26,174.3	104,245.3	1,010,340.8
Q_2	70,235.8	1,150,895.2	409,399.4	1,630,530.4	12,112,987.0
m	4.802254 $\times 10^{-2}$	2.930678 $\times 10^{-3}$	8.238662 $\times 10^{-3}$	2.068593 $\times 10^{-3}$	2.134339 $\times 10^{-4}$
b	-1,000.85	-1,000.85	-1,000.85	-1,000.85	-213.27
Q_e	9,682.4	473,544.0	561,320.9	1,273,332.0	11,102,646.2
P_e	-535.88	386.95	3,623.68	1,633.15	2,156.41

Table B.14: Scenario 3b - Small Outbreak Supply/Demand

Appendix C

Appendix C - North American Animal Disease Spread Model (NAADSM)

C.1 Use of NAADSM in this thesis

The original intention was to use NAADSM to model FMD outbreaks in Canada and use the results for the partial equilibrium model. These results would provide the post-outbreak cattle populations used to determine the shifts in supply. Unfortunately we were not able to incorporate NAADSM due to a number of factors that will be discussed.

To create a model in NAADSM, you need to input a number of parameters. The first set of parameters specifies the type, geographic location (latitude and longitude) and number of head for each herd unit. Specific data for this at the farm level is not available publicly from Statistics Canada due to privacy concerns. The only public data listed the total number of animals and the total number of farms within each Census Subdivision. There was also a breakdown of the number of farms that fell with a range of herd sizes. From this high level data the location and size of each herd needed to be determined. This was accomplished using a series of algorithms and GIS software to assign farm locations and herd sizes that matched the values found in the Statistics Canada data.

The next set of parameters required describe the various parameters of the disease being modelled. The parameters are grouped into categories as follows:

- Disease
- Disease Spread
- Detection
- Tracing
- Zones
- Destruction
- Vaccination
- Cost Accounting

Each of these categories can involve a number of parameters to be specified. For example, the Disease category requires data for Latent Period, Infectious Subclinical Period, Infections Clinical Period and Immune Period. The date type is usually a probability distribution function specified as a type with initial values.

Through consultation with others that have developed NAADSM models it was decided that developing our own parameters would require a considerable amount of time and expertise.

The next option was to find an existing model that had been parameterized. We were given permission to use an existing NAADSM model developed for the province of Alberta. It was developed by Arran Lamont, an MSc student attending the University of Alberta. The model is currently being refined by Caroline Dubé, an epidemiologist employed by the CFIA.[1] Unfortunately the model was not ready for us to use and would have delayed the completion of the thesis. Due to the time constraints it was decided to use the simplified approach that was incorporated in this thesis. However, the use of an existing NAADSM model is highly recommended for future researchers looking to extend the research found in this thesis.

[1]Thanks to Arran Lamont and Caroline Dubé for the offer to use their model.